बुढीगण्डकी जलविद्युत आयोजना विकास समिति
Budhigandaki Hydroelectric Project Development Committee

FEASIBILITY STUDY AND DETAILED DESIGN OF BUDHI GANDAKI HPP

PHASE 3: FINAL DETAILED DESIGN REPORT

Volume 1. Main Report

BG-DDR-Vol1-Rev0

TRACTEBEL Engineering GDF SUEZ
COYNE ET BELLIER Ingénieurs Conseils
jade CONSULT

बुढीगण्डकी जलविद्युत आयोजना विकास समिति

Budhigandaki Hydroelectric Project Development Committee

FEASIBILITY STUDY AND DETAILED DESIGN OF BUDHI GANDAKI HPP

PHASE 3: FINAL DETAILED DESIGN REPORT

Volume 1. Main Report

BG-DDR-Vol1-Rev0

TRACTEBEL Engineering GDF SUEZ

COYNE ET BELLIER Ingénieurs Conseils

jade CONSULT

0	01/11/15	Modification as per BGHPDC's comments	F. Dordé M. L'Hostis	P. Cazalis	P. Cazalis P. Cazalis
DRAFT	01/10/15	First Submission	F. Dordé M. L'Hostis	P. Cazalis	P. Cazalis
Revision	Date	Description	Written by	Checked by	Approved by

151001_BG_TE_R_Rev0_Final Detailed Design Report_Vol1_Main Report_Final.docx

ACKNOWLEGMENT

TRACTEBEL Engineering would like to express its deepest appreciation to all those who provided us the possibility to complete this study. It would not have been possible without the kind support and help of many individuals and organizations. We are very grateful for the level of cooperation and assistance provided by virtually every person whom we consulted.

We are highly indebted to Budhi Gandaki Hydroelectric Project Development Committee (BGHPDC), Nepal Electricity Authority (NEA), Ministry of Energy (MoEn), Survey Department, Department of Electricity Development Committee (DoED), Department of Mines and Geology (DMG), Department of Hydrology and Meteorology (DHM), Ministry of Land Reform and Management (MoLRM), Ministry of Forest (MoF), District Administrative Office, District Land Survey Office, District Land Revenue Office, Local Development Committee of Dhading and Gorkha Districts, VDCs Secretary, Community Forest Users Group Committee, Major Political Leaders, locals of Dhading and Gorkha Districts and others social elites for their guidance, suggestions and constant supervision as well as for providing necessary information regarding the project and also for their support in completing the project.

Our big thanks and appreciations goes to our subconsultants Jade Consult Pvt. Ltd, Nepal Environment Science Services Pvt. Ltd. (NESS), Fit Conseil , BRGM, ADM Carto, EMES Pvt. Ltd., High Himalayan Hydro Pvt. Ltd., Hydrolab Pvt. Ltd. and RECHAM Pvt. Ltd. for their kind and efficient co-operation and encouragement which help us in completion of this project smoothly.

We would also like to express our special gratitude and thanks to all the persons from Nepal and France who have willingly helped us out with their abilities.

***

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

Acronyms	**Definition**
CDP	Community Development Plan
CFRD	Concrete Face Rockfill Dam
CAOV3	Computer Assisted Design Version3 (French acronym)
DBM	Drill and Blast Method
D/S	Downstream
DCR	Design Concept Report
DFI	Development Finance Institution
EA	Executive Advisor
EAP	Environmental Action Plan
EIRR	Economic Internal Rate of Return
EPC	Engineering Procurement and Construction
ER	Employer’s Representative
FIDIC	International Federation of Consulting Engineers (French acronym)
FIRR	Financial Internal Rate of Return
FSL	Full Supply Level
GLOF	Glacial Outburst Flood
GoN	Government of Nepal
HEM	Hydro Electro Mechanical (Equipment)
HPP	Hydro Power Project
ICOLD	International Commission On Large Dams
IFI	International Financing Institution
INPS	Integrated Nepal Power System
IRR	Internal Rate of Return
IPVCDP	Indigenous People and Vulnerable Community Development Plan
LARRAP	Land Acquisition, Rehabilitation and Resettlement Action Plan
LDOF	Landslide dam outburst flood
LLO	Low Level Outlet
LiDAR	Light Detection and Ranging
MLO	Mid Level Outlet
MGC	Marginal generation Cost
MOL	Minimum Operating Level
MDE	Maximum Design Earthquake
NGO	Non-Governmental Organization
OBE	Operation Basic Earthquake
OECD	Organisation for Economic Co-operation and Development
PFR	Pre-Feasibility Report
PMF	Probable Maximum Flood
PMU	Project Management Unit
RCC	Roller Compacted Concrete
ROM	Reservoir Operation Model

Acronyms	Definition
RoE	Return on Equity
ROR	Run-Off River (Plant)
SC	Steering Committee
SEE	Safety Evaluation Earthquake
SPV	Special Purpose Vehicle
TBM	Tunnel Boring Machine
TIC	Total Investment Cost
U/S	Upstream
USBR	United States Bureau of Reclamation

1. INTRODUCTION

1.1. Background

Of the total installed capacity of 787 MW in the Integrated Nepal Power System (INPS), the Kulekhani HEP (1 and 2) (60 MW + 32 MW = 92 MW) is the only storage hydropower plant capable of seasonal regulation. The existing peaking capacity is insufficient to meet the peaking demand in the system. This is shown by the severe capacity and energy shortage during the dry season. Most of the plants that are being implemented or committed/planned are Run of River (ROR) plants. With the addition of more ROR plants, there will be an increasing surplus of energy during the wet season and a deficit in the dry season. The seasonal fluctuation of water discharge in the rivers of Nepal is the main cause for this imbalance. The dry season flow becomes almost one tenth of flows in the wet season. As a result, INPS will continue to be a sub-optimal system in the absence of peaking plants, resulting in the spilling of water during the wet season at ROR plants and capacity deficit during the dry season. A storage project of sufficient capacity is an ideal remedy for such a situation.

1.2. Recall of the Project location and context

The Budhi Gandaki Hydropower Project is located on the Budhi Gandaki River, approximately 2km from its confluence with Trishuli River at Benighat. Benighat can be accessed by the Prithivi Highway linking Kathmandu and Pokhara about 80km from Kathmandu (Figure 1-1). The Project area lies in the districts of Gorkha and Dhading of Western and Central Development Region of Nepal.

The Budhi Gandaki Hydroelectric Project is a large seasonal storage-type project able to fully store the monsoon inflows and release them later during the dry months. Therefore this Project responds perfectly to the urgent need of power regulation, especially during the dry season from mid-December to mid-May.

A prefeasibility study was carried out in 1983-1984 by the Government of Nepal. It recommended designing a 225m high rockfill dam with clay core, in a narrow and steep valley, retaining a reservoir of 3,320 hm^3 with its FSL at El. 520. The underground powerhouse connected to the reservoir by a 276m long headrace tunnel was designed with four Francis turbines rated for a net head of 185m and a discharge of 4 x 107.5 m^3/s thus providing a total installed capacity of 600MW and generating an average annual energy of 2,495GWh . The study concluded that the project has a high energy potential, large storage volume, and favorable location and access in Central Nepal near the main load center.

Subsequently, in 2010-2011, NEA carried out additional studies including:

- A review of national development plans,
- Topographical survey works in the reservoir,
- A revised estimation of the households directly impacted by the reservoir,
- The introduction of an alternative waterway,
- A review of the energy production with new reservoir simulations studies,
- The installation of new gauging and meteorological stations, hydrological and solid transport measurements and sampling,
- Identification of further studies.

After a tendering and selection process of International Consulting Firms NEA has awarded in December 2012 to TRACTEBEL Engineering SA France in association with JADE Consult (Pvt) Ltd Nepal as a sub consultant, the Contract for the Feasibility Study and Detailed Design and Tender Documents of the Budhi Gandaki Hydropower Project. The complete duration of the study was 30 months which has started with an Effective Date of Commencement of the Services on February 1, 2 013. Further to the devastating earthquake which occurred on April 25th 2015 the original schedule for the completion of consulting services on July 31st, 2015 was postponed to October 31st, 2015 by the Budhi Gandaki Hydroelectric Project Development Committee who officially granted an extension of time of 3 months to TRACTEBEL Engineering SA France.

The main objective of the Feasibility and Detailed Design study was to prepare the project for implementation from the current status of pre-feasibility study. The overall objective of the consulting service was to carry out the necessary field investigations and upgrade the existing pre-feasibility study of Budhi Gandaki Hydropower Project to a feasibility level, prepare a de tailed design and tender documents and tender drawings, and prepare in association with NESS Pvt Ltd Nepal the Environmental Impact Assessment, the Social Impact Assessment, the Environmental Management Plan and Construction Plan to meet the NEA, GoN and leading multilateral agencies requirements for construction of the project.

The 33 months study was divided in three Phases:

- Phase 1: Selection of Optimized Design Concept — February 2013 to February 2014
- Phase 2: Feasibility Study of the selected layout — March 2014 to October 2014
- Phase 3: Detailed Design and Tender Documents — November 2014 to October 2015

The Field Investigations and Laboratory tests have been carried out in parallel during these three phases.

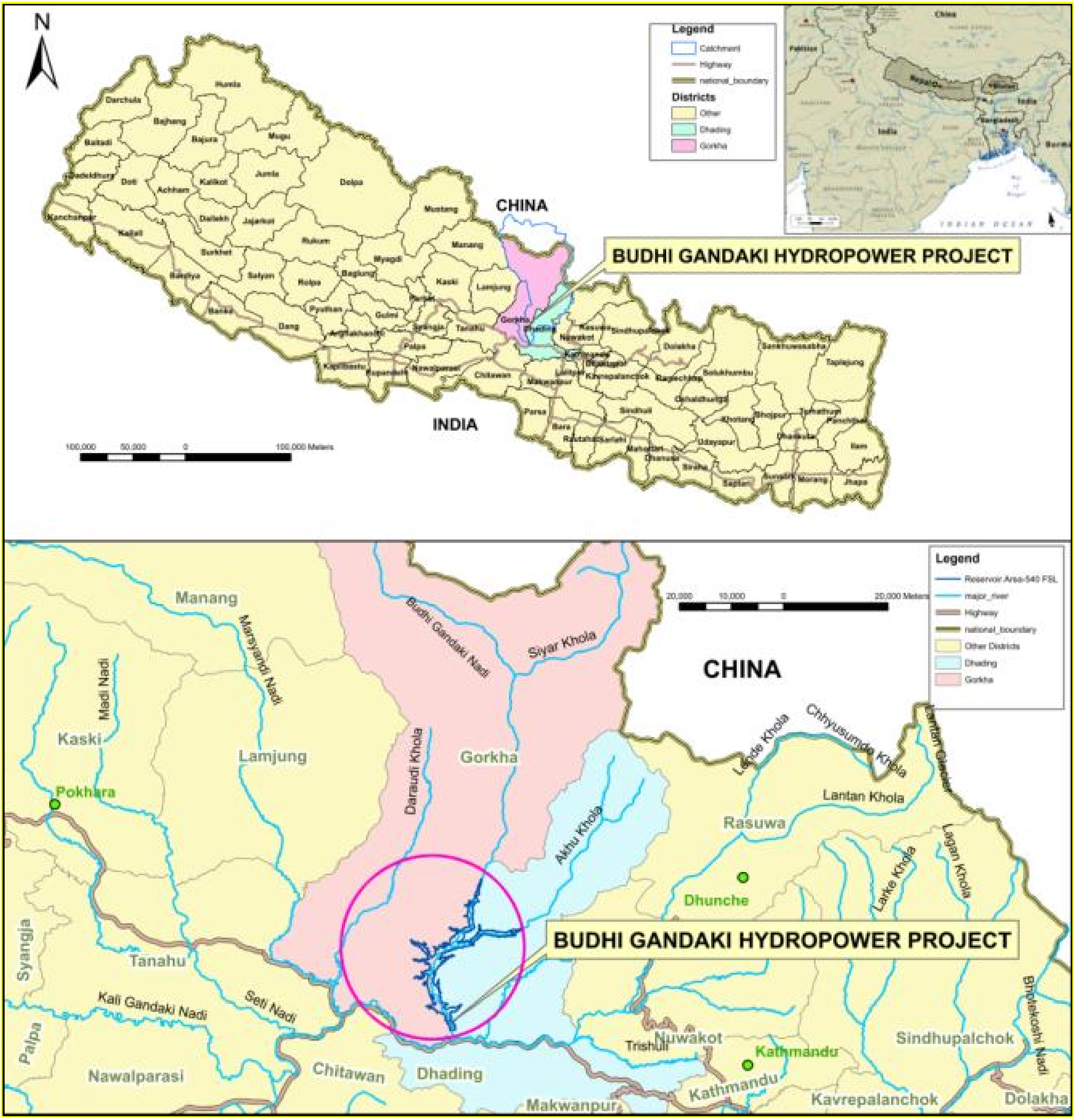


Figure 1-1: Localization of the Project

1.3. Recall of Phase 1 – Design Concept Report

The objective of the Phase 1 - Design Concept Report was to select the Best Design Concept (Full Supply Level FSL, rated discharge, layout) taking into account:

- The Preliminary Social/Environmental Impacts and Costs;
- The Valorisations of the Energy produced;
- The Cost of the Construction of the Project.
- The risks (financial and construction time) associated with selected layout Options.

On the basis of the data collected at that time, all the possible technical options were studied in the Phase 1 Design Concept Report regarding:

(i) General layout scheme, type of dam, Intake, location of the powerhouse etc.;

(ii) Reservoir level;

(iii) Reservoir Operation rules

(iv) Installed capacity of the scheme (Energy generation studies, rated discharge), etc.

Three main layout options considering different waterways and powerhouse locations were studied and compared:

Option 1: Powerhouse at the Toe of the dam releasing water directly in the Budhi Gandaki River;

Option 2: Powerhouse in Benighat releasing water with a short tunnel in the Trishuli River. This was the scheme selected in the 1983-84 PFR;

Option 3: Powerhouse in Phisling, releasing the water with a long tunnel in the Trishuli River in Phisling. This was the alternative layout proposed in the Prefeasibility Review NEA of 2011.

The Figure 1-2 below presents schematically the three layout Options analysed and compared in the Phase 1 DCR.

A multi criteria analysis has been carried out for comparing the three layout options. The criteria which have been considered fall into the following categories:

- Topographical constraints
- Geological constraints
- Hydraulic constraints
- Construction and schedule constraints
- Benefits and Costs
- Compensation Reservoir D/S of Budhi Gandaki
- Environmental and Social Impacts

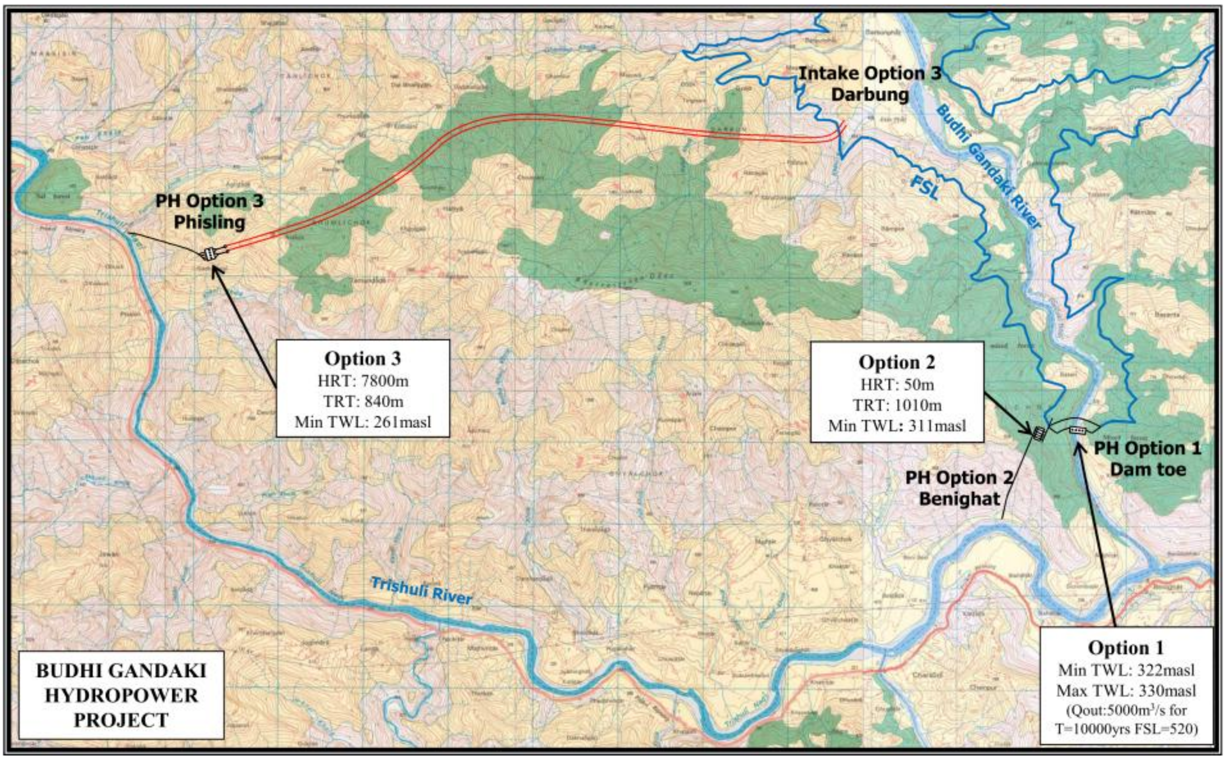


Figure 1-2: Overview of the project site and Phase 1 – waterways layout options

Finally, in the Design Concept Report Ref BG-DCON-Vol1 to Vol6, TRACTEBEL Engineering recommended the **Option 1: Powerhouse at the Toe of the dam releasing water directly in the Budhi Gandaki river**, with the following characteristics and costs:

- Reservoir: Full Supply Level at El.540 masl, generating a reservoir volume of 4 467 million m^3 out of which the active storage represents 2 226 million m^3.
- Concrete Arch Gravity dam of 263 m height above foundation level.
- Powerhouse at the dam toe with an installed capacity of 945 MW implemented in two steps:
  - Step 1 : 630 MW in 4 units
  - Step 2: 315 MW in 2 units
- Project Total Cost: Step 1: 2 125 MUSD
  Step 2: +105 MUSD
  2 230 MUSD

With letter 2070/71 Ref. 323 dated March 21, 20 14 the BGHPDC approved the recommended options and instructed TRACTEBEL Engineering to proceed further with the Phase 2 Feasibility Study of the selected scheme and the Field and Tests Investigations as required for supporting the study. See Figure 1-3 below.

Government of Nepal
Budhigandaki Hydroelectric Project Development Committee
Tripureshwor, Kathmandu

Ref: 323/70/71

Date: March 21, 2014

Mr. Philippe CAZALIS
Team Leader
Budhigandaki Hydroelectric Project
TRACTEBEL Engineering S. A. France
Thapathali, Kathmandu

Subject: Selection of Option 1

References:

1. Contract Agreement between NEA and TRACTEBEL ENGINEERING S.A. FRANCE dated 2nd December 2012 for the Feasibility Study and Detailed Design of BudhiGandaki Hydropower Project
2. Transfer and Assumption Agreement signed on November 10, 2013 between NEA, Development Committee and TRACTEBEL Engineering S.A
3. Your Office letter no. BGHPP/2014/PCZ-0154 dated March 1, 2014
4. Your Office letter no. BGHPP/2014/PCZ-0156 dated March 6, 2014
5. Inception Report BG-IR Rev 1

Dear Sir,

Budhigandaki Hydroelectric Project Development Committee congratulates and appreciates the timely submission of Phase 1-Design Concept Report and Investigation Reports.

As per the Contract Agreement, we are happy to bring it to your attention that the Option 1 (Power House in the Dam Toe or outside close to the Dam) with the recommended FSL and Design Discharge has been selected by the Committee for 2nd Phase Study. Further, with regard to PCZ-0156, the selection of the Option 1 ends the investigations related to Option 2 and Option 3.

We believe that the study works shall smoothly move ahead for the Phase 2 as well.

With Best Regards

received on 24/03/14
P. CAZALIS

Dr. Laxmi Prasad Devkota
Executive Chairman

Saraswoti Marg 161, Tripureshwor, Kathmandu, Nepal, Ph: 4219798, 4219799, Email: info@bghep.gov.np, Web: www.bghep.gov.np

Figure 1-3 : BGHPDC letter 2070/71 Ref. 323 dated March 21, 2014 – Approval of the options recommended in the Design Concept Report

1.4. Recall of Phase 2 – Final Feasibility Report

During the Phase 2 corresponding to the Feasibility Study of the Project, all the components of the scheme have been optimized, defined and drawn at a feasibility design level allowing to estimate the costs, to prepare the construction schedule, the implementation modalities, to identify and analyse the impact on the downstream facilities and finally to evaluate the economic viability and profitability of the scheme.

All the necessary information, analysis, conclusions and drawings on the Project Feasibility have been presented in the Phase 2-Final Feasibility Report submitted, after incorporating BGHPDC's comments, in four Parts and in 25 copies on February 1st 2015 i.e. 24 months after the commencement of the services**.**

For ready reference, the Phase 1 Design Concept Report previously submitted 13 months after the date of commencement of the services i.e. in March 1st, 2014 has been reproduced *in extenso* in the PART 4 of the edition of the **Phase 2- Final Feasibility Report** which detailed content is reproduced here below:

PART 1

- Volume 1 - Feasibility Report and Executive Summary — BG-FFR-Vol 1-Rev0
- Volume 2 - Hydrological and Meteorological Analysis — BG-FFR-Vol 2-Rev0
- Volume 3 - Assessment of Downstream Impacts — BG-FFR-Vol 3-Rev0
- Volume 4 - Reservoir Simulation Studies — BG-FFR-Vol 4-Rev0
- Volume 5 - Sedimentation Study — BG-FFR-Vol 5-Rev0
- Volume 6 - Geotechnical, Geological and Seismic Hazard Analysis — BG-FFR-Vol 6-Rev0

PART 2

- Volume 7 - Choice of Dam alternative — BG-FFR-Vol 7-Rev0
- Volume 8 - Design of the Dam — BG-FFR-Vol 8-Rev0
- Volume 9 - Spillway and other Hydraulic Structures Design — BG-FFR-Vol 9-Rev0
- Volume 10 -Design of the Intake, the Waterways and the Powerhouse — BG-FFR-Vol10-Rev0
- Volume 11 -Electromechanical, Hydro Mechanical and Electrical Equipment — BG-FFR-Vol 11-Rev0
- Volume 12 -Power Evacuation Study — BG-FFR-Vol 12-Rev0
- Volume 13 -Design of the Preparatory Works — BG-FFR-Vol 13-Rev0
- Volume 14 -Investment Cost and Construction Planning — BG-FFR-Vol 14-Rev0
- Volume 15 -Economic and Financial Analysis of the Project — BG-FFR-Vol 15-Rev0

PART 3

- Volume 16 -Engineering Drawings — BG-FFR-Vol 16-Rev0

PART 4

- Phase 1 - Design Concept Report — BG-DCON-Vol1 to Vol6

1.5. Phase 3 – Detailed Design Report and Tender Documents

The main objective of the Final Detailed Design Report is to allow the production the Tender Documents to prepare the bid for construction. For that purpose, TRACTEBEL Engineering has conducted the detailed design studies i) for the civil works of the whole Project including the preparatory works (permanent roads, bridge, Owner's camps), ii) for the Hydro-Mechanical and Electro-Mechanical Equipment incorporated in the power plant and in the dam and iii) for the Transmission lines.

The Detailed Design includes also the quantity estimates, the detailed cost and the construction planning and scheduling suitable for construction bidding and also for presenting to the international and national financing agencies for funding purpose.

The Final Detail Design Report is presented in 16 Volumes as follows:

VOLUME 1 – Main Report	BG-DDR-Vol1-Rev0
VOLUME 2 – Hydrology and sedimentology	BG-DDR-Vol2-Rev0
- *VOLUME 2A – Hydrological and Meteorological Analysis*	*BG-DDR-Vol2A-Rev0*
- *VOLUME 2B – Assessment of Downstream Impacts*	*BG-DDR-Vol2B-Rev0*
- *VOLUME 2C – Reservoir Simulation Studies*	*BG-DDR-Vol2C-Rev0*
- *VOLUME 2D – Sedimentation Study*	*BG-DDR-Vol2D-Rev0*
VOLUME 3 – Geotechnical Geological and Seismic Hazard Analysis	BG-DDR-Vol3-Rev0
VOLUME 4 – Diversion Works	BG-DDR-Vol4-Rev0
VOLUME 5 – Double Curvature Arch Dam	BG-DDR-Vol5-Rev0
VOLUME 6 – Spillway, Mid-Level and Low-Level Outlets	BG-DDR-Vol6-Rev0
VOLUME 7 – Intake and Waterways	BG-DDR-Vol7-Rev0
VOLUME 8 – Power House Civil Works	BG-DDR-Vol8-Rev0
VOLUME 9 – Hydraulic Steel Structures	BG-DDR-Vol9- Rev0
VOLUME 10 – Power House Electromechanical and Dam Electrical Equipment	BG-DDR-Vol10- Rev0
VOLUME 11 – 400kV Substation	BG-DDR-Vol11- Rev0
VOLUME 12 – Transmission Lines	BG-DDR-Vol12- Rev0
VOLUME 13 – Grid Impact Study	BG-DDR-Vol13- Rev0
VOLUME 14 – Design of the Preparatory Works	BG-DDR-Vol14- Rev0

VOLUME 15 – Investment Cost, Construction Planning, Institutional Arrangement, Financing and Contract Setup BG-DDR-Vol15- Rev0

VOLUME 16 – Economic and Financial Analysis of the Project BG-DDR-Vol16- Rev0

VOLUME 17 – Detailed Engineering Drawings BG-DDR-Vol17- Rev0

The Tender Documents have been prepared with all the necessary detailed drawings, technical specifications, employer's requirements, bill of quantities, and all the required general and particular bidding documents.

The Tender Documents submitted to BGHPDC in a separate set of document have been structured in three LOTS as per the recommendation of TRACTEBEL Engineering detailed in the Final Feasibility Report, recommendation subsequently approved by BGHPDC with letter Ref 072/73 N°158 dated September 14, 2015:

- **LOT N°1**: Camp facilities, Access roads and Bridge
- **LOT N°2**: Dam and Appurtenant Structures
- **LOT N°3**: Power Plant and Waterways

The LOT N°2 includes the river diversion works and the LOT N°3 includes the transmission lines and substations.

The Lot N°1 is a quantity based Contract, structured as per the guidelines of the FIDIC red book whereas the LOT N°2 and 3 are EPC/turnkey type Contracts based as per the guidelines of FIDIC silver book.

1.6. Field Investigations and Laboratory Testing

The Field Investigations and Laboratory Testing campaigns carried out in Phase 1 have been extended into the Phase 2 and also Phase 3 of the study with a focus on the selected layout Option 1 as defined in the Phase 1- Design Concept Report.

The Extensive Field Investigation campaign carried out between 2013 and 2015 included namely:

- 896m of investigation adits in the dam abutments,
- 12 large scale plate jacking tests and 500m of Scarabee ® or "*petite sismique*" method in the investigation adits,
- 1837m of core drilling in the dam and powerhouse foundation including permeability tests and dilatometer tests,
- 125 km^2 of LiDAR topographic survey covering the reservoir, the dam and the power house areas,
- 100km of transmission line corridor survey,
- 6km of seismic refraction survey,

- 431 river bathymetric sections,
- Establishment of a Survey Control Network with 20 permanent new monuments,
- 24 months of river gauging stations monitoring including 78 r iver flow measurements,
- 24 months of climatological stations monitoring,
- More than 600 sediment samples including 54 large samples extracted with pump sediment sampling method,
- 1 Hydraulic Model - scale 1 :100,
- Numerous laboratory tests on core samples and construction materials.

All the field investigations and laboratory test results (Phase 1, Phase 2 and Phase 3) are included in the **Final Field Investigation Report** (Ref BG-INV-FNL A/B/C-Rev0) submitted on November 1st, 2015. It contains all the results from site investigations and laboratory tests. This report is presented as follows:

- Part A - Topographical and Bathymetric Survey Ref. BG-INV-FNL-A Rev0
- Part B - Hydrological, Meteorological and Sedimentological Investigations & Hydraulic Model Studies; Ref. BG-INV-FNL-B Rev0
- Part C - Geological, Geotechnical and Seismological Investigations. Ref. BG-INV-FNL-C Rev0

2. BASIC DATA AND INFORMATIONS

2.1. Climate and Hydrology

The Budhi Gandaki basin is part of the Narayani drainage system and is bordered in the north by the vast Tibetan Plateau, in the south and east by the Trishuli River basin and in the west by the Marsyangdi River basin. With a total area of 5 005 km^2 the catchment area of the Budhi Gandaki HPP is characterized by a large range of elevation, from green hills in the south to snow covered Himalayan peaks in the north.

The mean annual basin rainfall is 1 495mm with a high spatial variability. The mean annual discharge of the Budhi gandaki River at the dam site is estimated to **Q_{mean}=222m^3/sec** and the corresponding mean annual volume to 6 990 Mm^3. See Figure 2-1.

The Budhi Gandaki river, like all rivers in Nepal, shows a marked seasonal variability of the discharge with high discharges in the monsoon and relatively low discharges in the dry season as illustrated in the Figure 2-2.

The flood analysis concludes that the 10 000 years flood is about **$Q_{10'000}$=6 260m^3/sec** and the Probable Maximum Flood about **Q_{PMF}=9 800 m^3/sec**.

Glacial outburst floods and landslide dam outburst floods have been estimated but the corresponding peak discharges at dam site are significantly less than the Probable Maximum Flood and are therefore not governing values for the design of the dam and spillway structures though conservative combination of floods have been considered.

Reference is made to VOLUME 2A – H ydrological and Meteorological Analysis BG DDR Vol2A of the present study for detailed data and information.

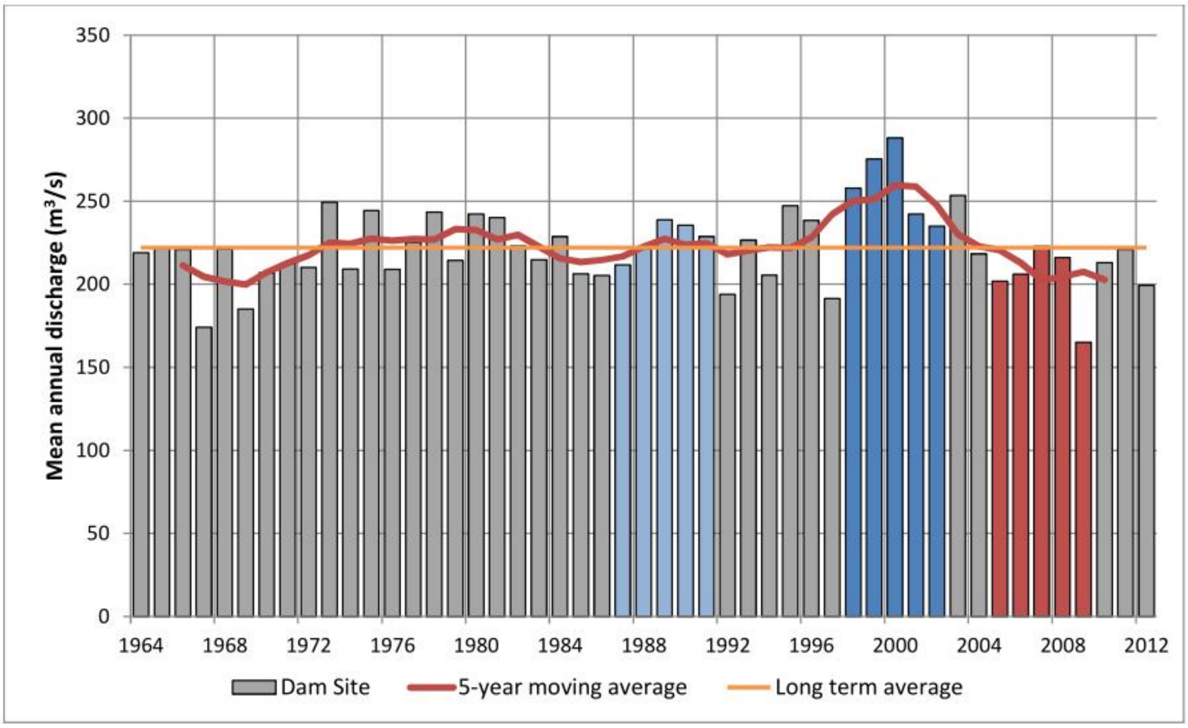


Figure 2-1: Budhi Gandaki - Mean annual discharge 1964-2012 at dam site

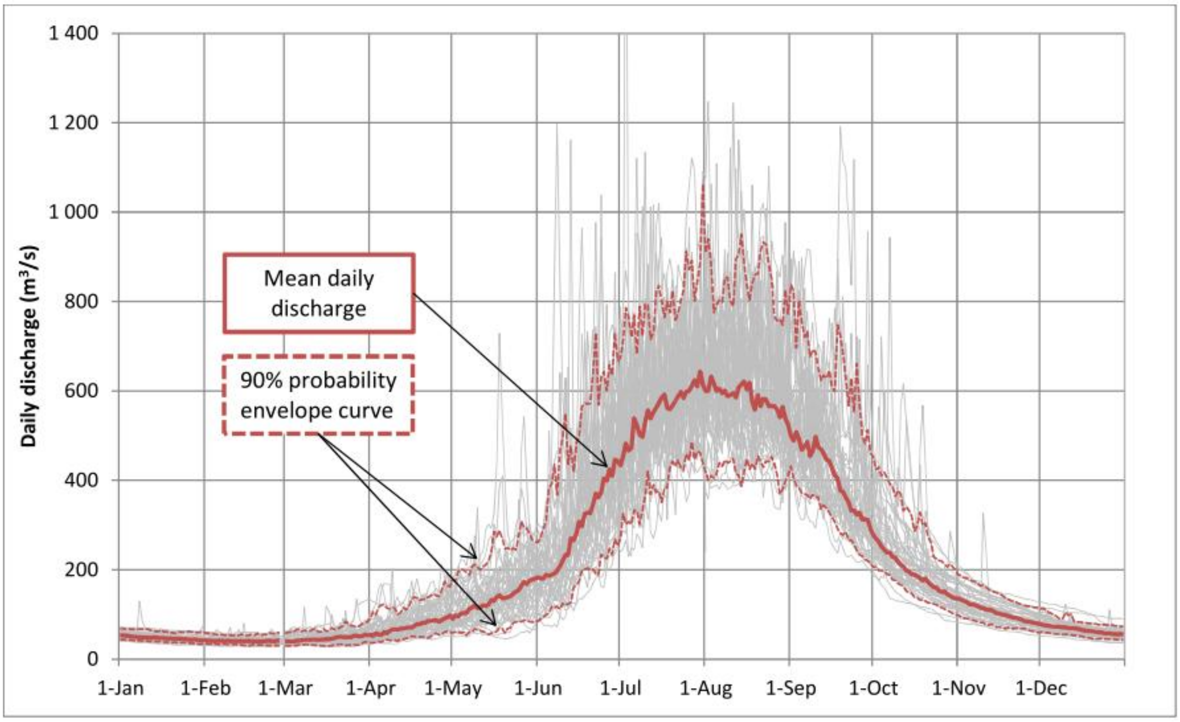
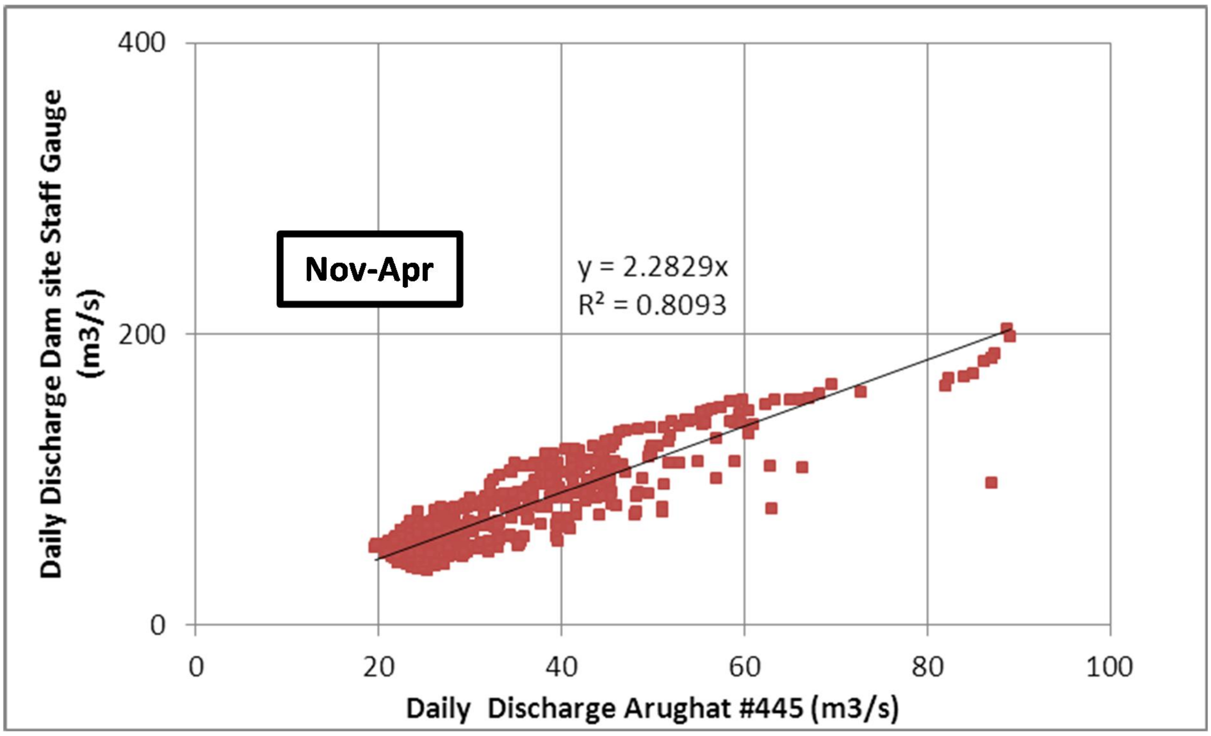


Figure 2-2: Budhi Gandaki-Yearly distribution of daily discharges at dam site

A major concern throughout the various stages of the studies has been to take advantage of the results of the river discharge monitoring operated since 2010. The more recent results for years 2013 and 2014 are consistent with the previous years and confirm that the inflows assessment was carried out on the conservative side[1]. They suggest that the river inflows could be larger than previously estimated at the time of the feasibility study. A brief overview of the additional hydrological analysis is presented hereafter. It is highly recommended to maintain the river discharge monitoring program.

The daily discharge series 2010-2014 at Arughat gauging station and at the dam site (Kalleri suspension bridge) are plotted in the figure hereafter. A sound relationship between daily discharges is observed as long as 2 seasons are separated corresponding to the low flow (November to April) season and the high flow (May to O ctober) seasons. The correlation coefficients are high, respectively 0.81 and 0.90.

[1] The Feasibility Report has adopted a conservative approach in the transposition law between discharges measured at Arughat DHM long term operated gauging station (since 1964) and those measured at the dam site since only few years (2010-1013) of parallel measurements were available when editing the Feasibility Report.



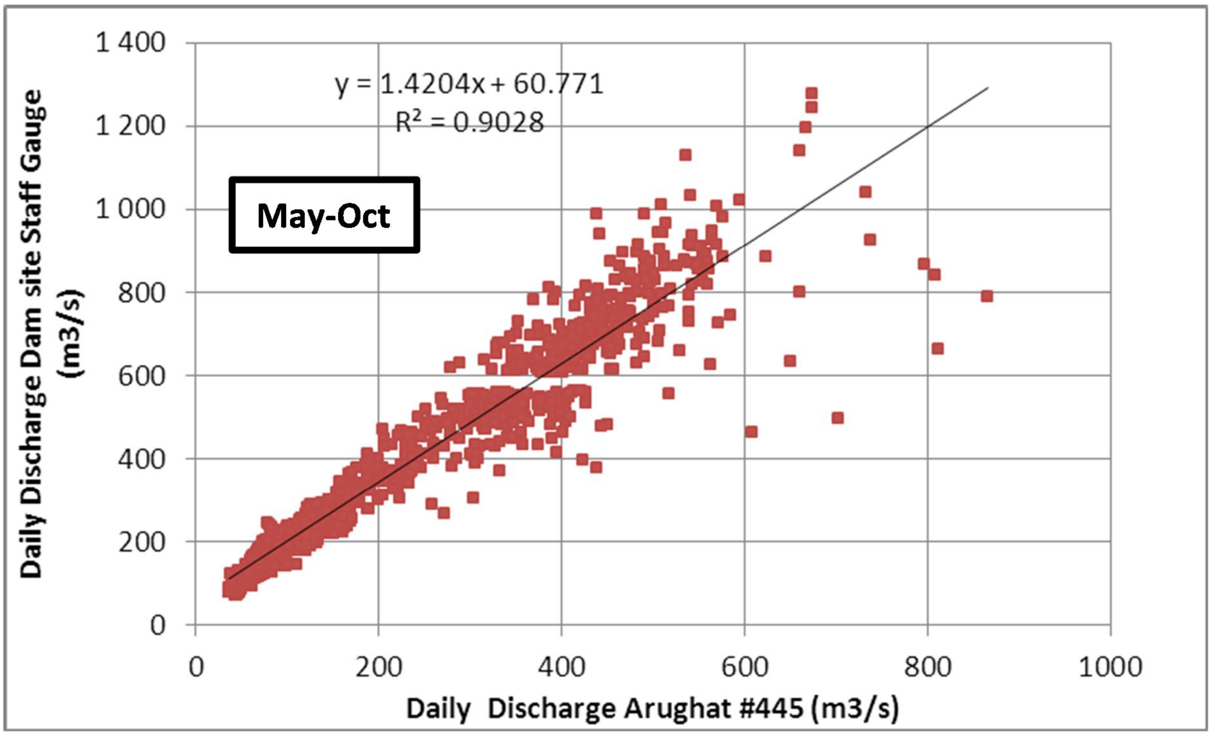


Figure 2-3 : Daily discharge series at Arughat and dam site (2010-2014)

Previous relationships are applied to derive the daily discharge series at the dam site from the series at Arughat gauging station for the entire period 1964-2014. The series derived from this calculation is very close to the series derived from the observations at the dam site (Kalleri suspension bridge) (Figure 2-4). The discharge-discharge relationship is thus reliable and is used to derive a long-term (1964-2014) series of inflows at the dam site. Inflows estimates are found to be larger than at the time of the phase 2: feasibility study

(+26%). This has a direct impact on the Project generation output as detailed in the following section 4.4.

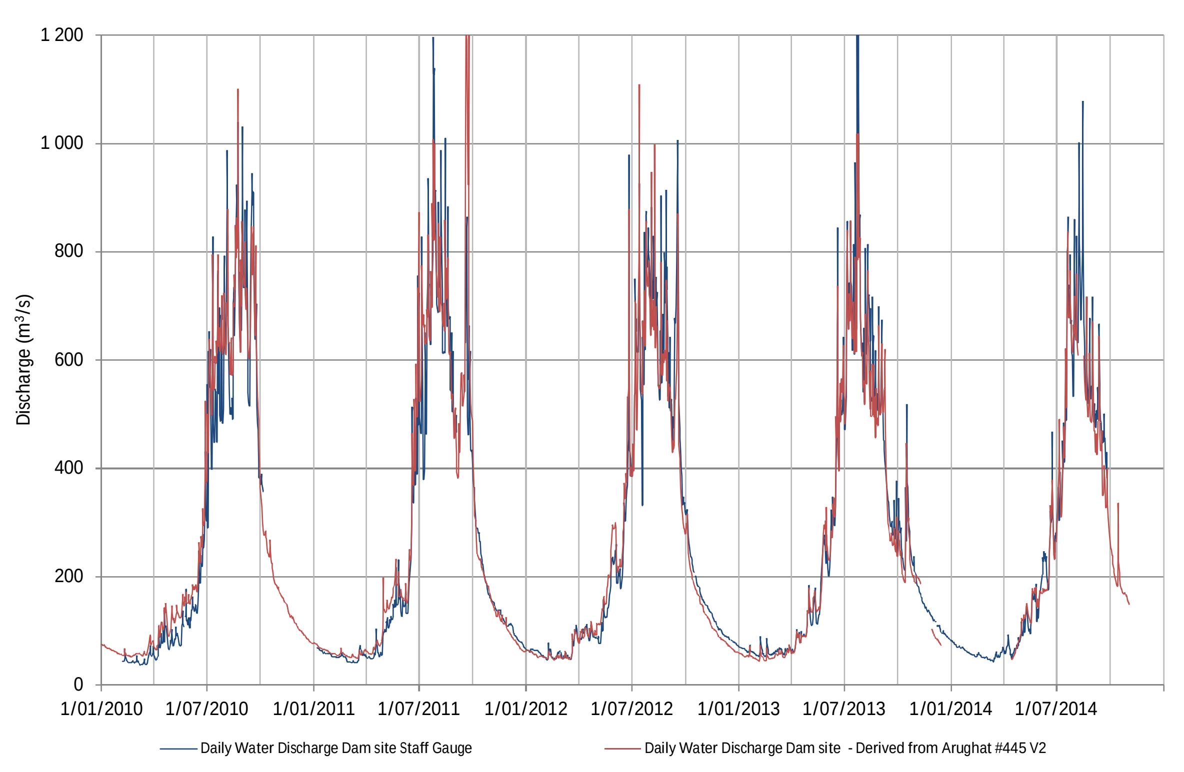


Figure 2-4 : Daily discharge series at the dam site (2010-2014)

2.2. Sedimentology

A sediment rating curve (sediment discharge vs. river discharge) based on a 3- year sediment sampling programme was applied to long term river discharge (1964-2012) and was used to estimate mean annual sediment inflow to the Budhi Gandaki reservoir. Almost 600 measurements (including 54 large samples taken during the monsoon 2014 with the pump sediment sampling method newly implemented in Nepal on the Budhi Gandaki project) of suspended sediment concentration and river discharge were used in the development of the relationships for the high flow and low flow seasons. Sediment inflow to the Budhi Gandaki reservoir was estimated to be 7.6±2.2 million m3/year. The volume of sediment due to rare catastrophic events such as LDOFS or GLOFS was estimated to be about 2 million m3 for an extreme event. **In a conservative approach, the upper limit of estimated sediment inflow equal to 9.8 million m3/year is therefore considered as the annual sediment inflow to the Budhi Gandaki reservoir**. Of this amount, an estimated 9.6 million m3 of sediment per year (467 million m3 after 50 years) will be deposited in the reservoir without a sediment management strategy. The empirical USBR method, based on observations in existing reservoirs, was used to estimate the deposition patterns in the Budhi Gandaki reservoir. The sediment elevation estimated by this method (depth at which no reservoir capacity is available) after 50 years is El.364.5 masl i.e. 95 m below the power intake invert level which is at El.450 masl.

Sediment deposition will occur in both the dead and the active storages of the reservoir, however the results of the sedimentation study indicate that **only about 7% of the active storage will be lost after 50 years and about 13% of the active storage will be lost after 100 years.** See Figure 2-5 and Table 2-1 below.

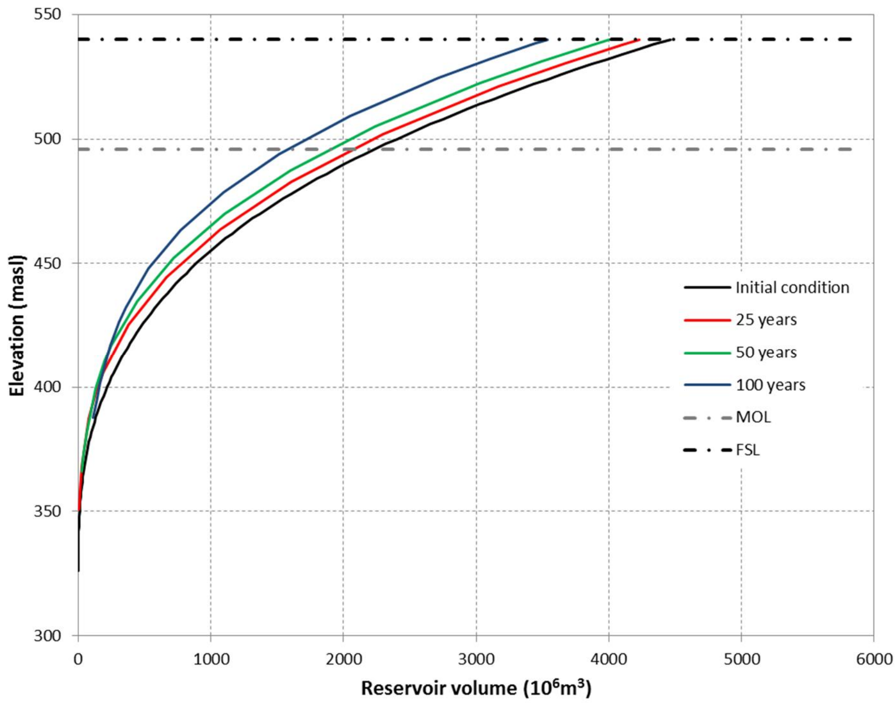


Figure 2-5: Cumulative volume of sediment in the Budhi Gandaki reservoir

	Initial condition	After 25 years	After 50 years	After 100 years
	Reservoir volume (Mm^3)	Reservoir volume (Mm^3)	Reservoir volume (Mm^3)	Reservoir volume (Mm^3)
Elevation 496 m (MOL)	2241.6	2088.5	1915.9	1590.6
Elevation 540 m (FSL)	4467.3	4231.0	3998.6	3538.3
Live storage	2225.7	2142.5	2082.7	1947.7
Loss of live storage		83.2	143.0	278.0
%Loss of live storage		***3.7%***	***6.4%***	***12.5%***

Table 2-1: Estimated loss of live storage with time in the Budhi Gandaki reservoir

Sluicing of sediments during the rising limb of the annual flood hydrograph in July is recommended as the sediment management strategy for the Budhi Gandaki reservoir. For such operations, the dam will be equipped with outlets at elevation El.440 masl. The forecasting of flood inflows with a g ood level of confidence will be useful in the implementation of this strategy by dam operators. The proposed method of sediment management will also help to mitigate possible negative downstream impacts on the Budhi Gandaki River due to sediment trapping in the reservoir.

2.3. Tailwater rating curves

The rating curves on Budhi Gandaki river are determined according to a one dimensional hydraulic model.
In order to have an exhaustive approach of the water levels at the Budhi Gandaki river, two parameters were studied in details. The first point is the influence of the Trishuli river within the Budhi Gandaki river. Since the levels on the Budhi Gandaki river at powerhouse and dam site are not significantly higher than at the confluence with the Trishuli river, there is a backwater effect from the Trishuli to the Budhi Gandaki. In fact, high water levels at confluence may impose the water level in Budhi Gandaki since the bathymetric elevation in the river is moderate compared to Trishuli bathymetric levels at confluence.
In order to take into account this influence, we studied the daily measured data on these two rivers. The following figure represents the daily discharge on the Budhi Gandaki and Trishuli rivers measured during several years :

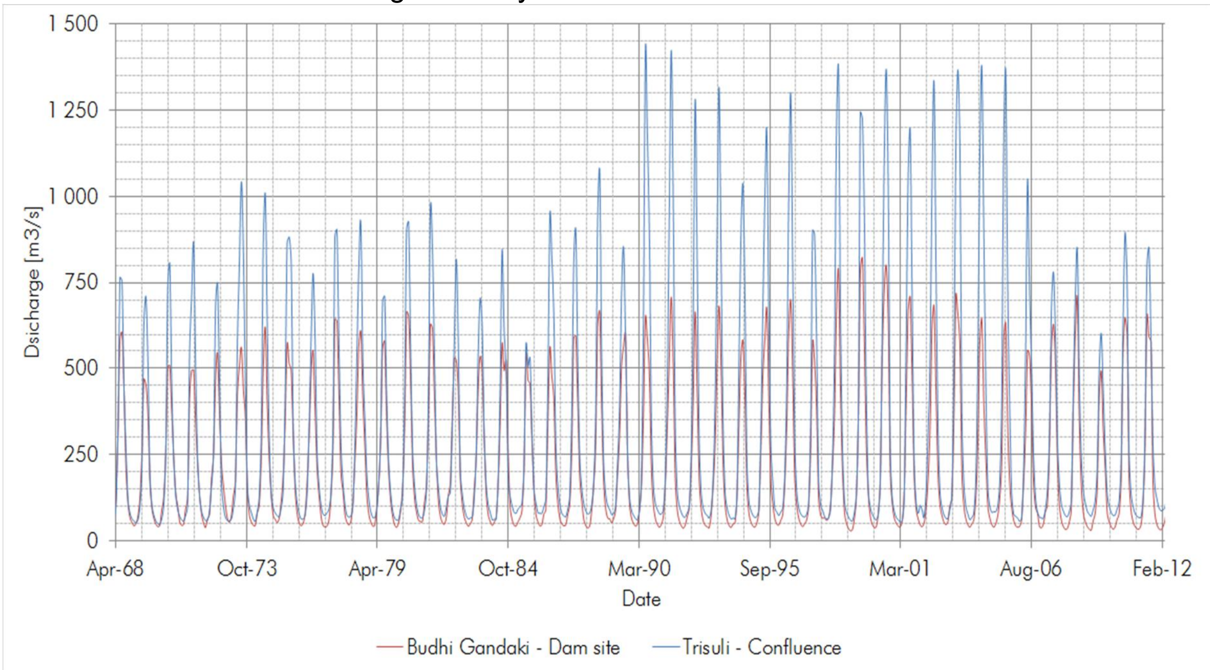


Figure 2-6: Measured discharge - Budhi Gandaki and Trishuli rivers

The maximum measured discharge is below 1 500 m^3/s, but since we want to compute the rating curves for larger discharges, we made a statistical analysis of the 2 ca tchment basins.

By setting a Fr ancou-Rodier analysis, it allowed us to extrapolate the concomitant discharges in the 2 rivers up to a flood of about 10 000 m3/s, corresponding to the PMF.

This statistical adjustment allowed us to estimate 3 scenarios for each discharge on the Budhi Gandaki:

- An average estimation corresponding to the Francou-Rodier adjustment,
- A low estimation with a fixed reduction of 20% of the Trishuli corresponding discharge,
- A high estimation with a fixed increase of 20% of the Trishuli corresponding discharge.

With such adjustment, we get a range of probable discharges in Trishuli for each discharge on Budhi Gandaki. By this approach, we reduce substantially the exceedance probability of Trishuli discharge, and we improve the safety approach of the computation.

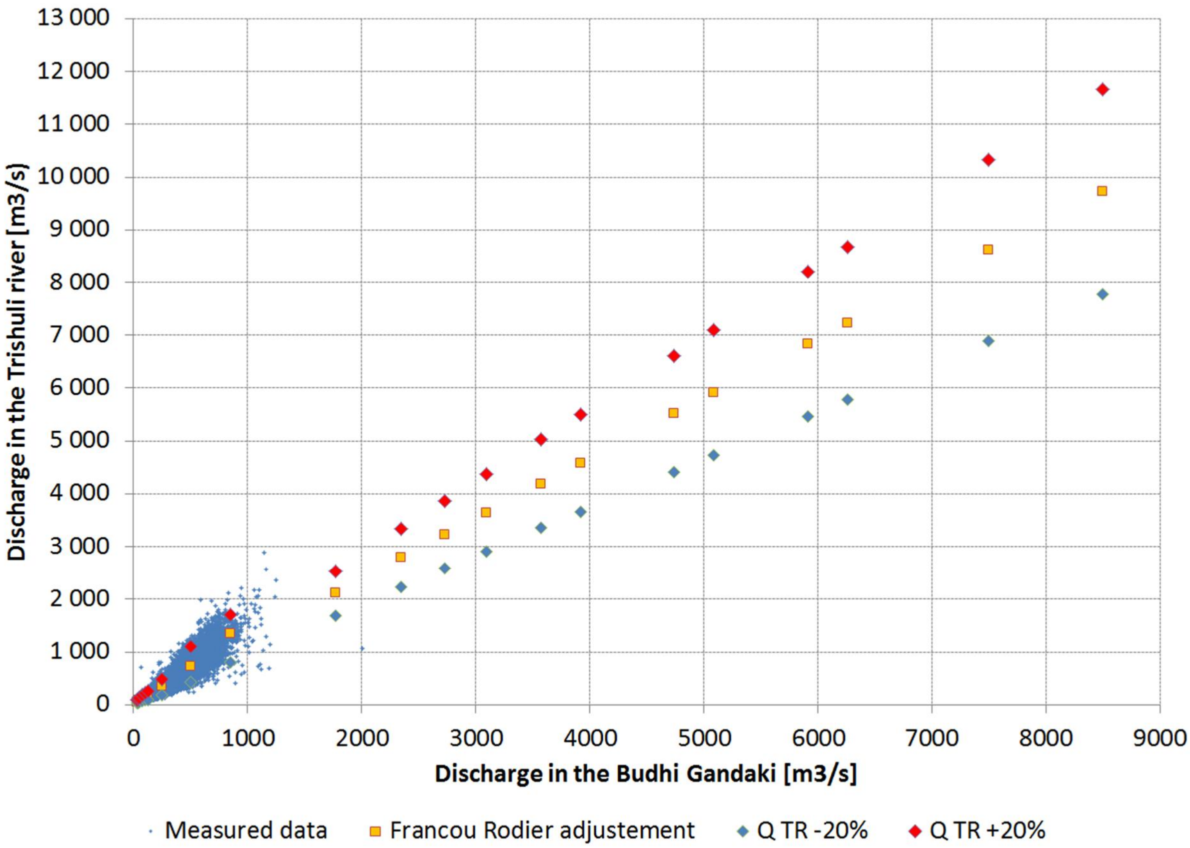


Figure 2-7: Determination of Trishuli discharges depending on Budhi Gandaki discharges

Moreover, given the uncertainty on the friction coefficient in the river, we performed a sensitivity analysis. We have defined a reasonable range of friction coefficient, for which we have computed several simulations. We defined the maximum and minimum friction coefficients as follows:

- A low Strickler coefficient of Ks=20 $m^{1/3}/s$,
- A high Strickler coefficient of Ks=35 $m^{1/3}/s$.

By crossing this sensitivity study with the estimations of probable discharges on Trishuli depending on Budhi Gandaki, we obtained 5 estimations of the rating curves according to 5 scenarios:

- Q Trishuli minimum, with Ks = 20,
- Q Trishuli minimum, with Ks = 35,
- Q Trishuli maximum, with Ks = 20,
- Q Trishuli maximum, with Ks = 35,
- Average scenario.

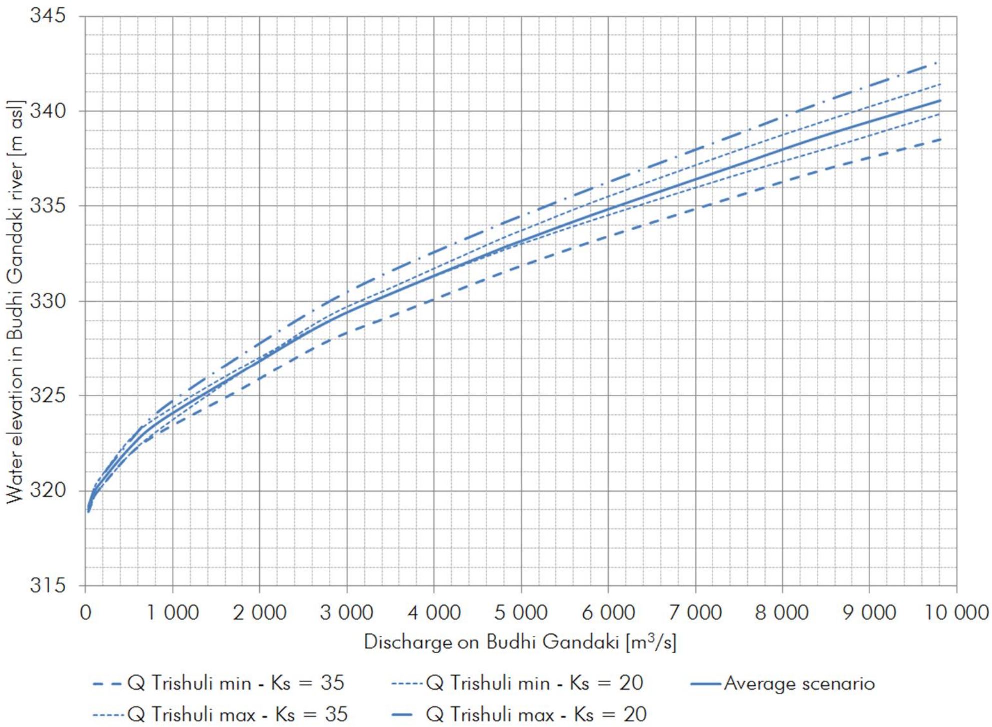


Figure 2-8: Budhi Gandaki rating curve at powerhouse area - According to various scenarios

In order to have a more comprehensive approach of the problem, we computed the theoretical rating curves without considering the Trishuli influence on Budhi Gandaki water levels at different locations:

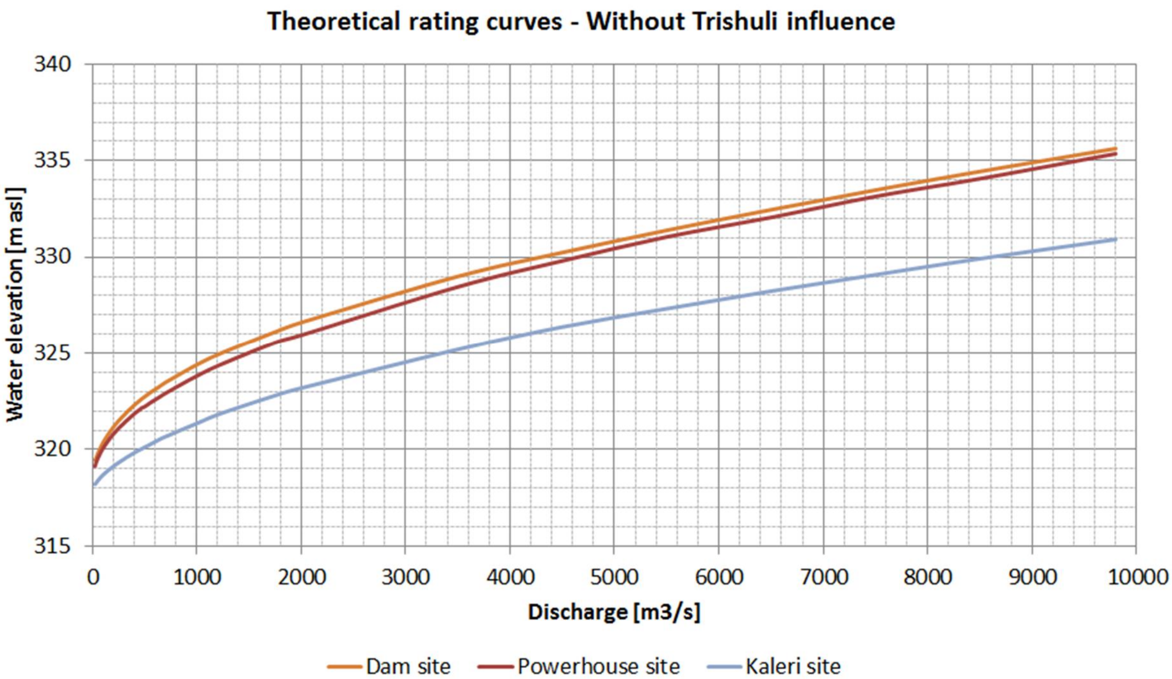


Figure 2-9: Theoretical rating curves - Without Trishuli backwater influence

2.4. Geology and Geotechnical investigations

The Dam and Appurtenant structures have been located, from geological and geotechnical point of view, in the most favorable stretch of the river. The bedrock consists of quartzite, phyllite and siliceous dolomite of the Nourpul formation. Quartzite and alternant quartzite-phyllite are predominant in the upstream part, where the dam is located. The structural setting is characterized by overturned stratigraphic sequence, with bedding strike near perpendicular to the river and dip towards upstream. The bedding dip is very steep at the river level and decreases in the upper part of the abutments.

The project site is delimited by two zones (see Figure 2-10) of intense tectonic deformation: to the north, the contact between the Nourpul and the Dandagaon formations; to the south, a regional fault zone identified during the Inception phase and named Budhi Gandaki – Mauwa Khola fault. Between the two deformation zones, the tectonic stress was accommodated mostly by second order fractures and shear zones, with different orientations and variable persistence. The resulting rock mass assembly consists of well interlocked blocks.

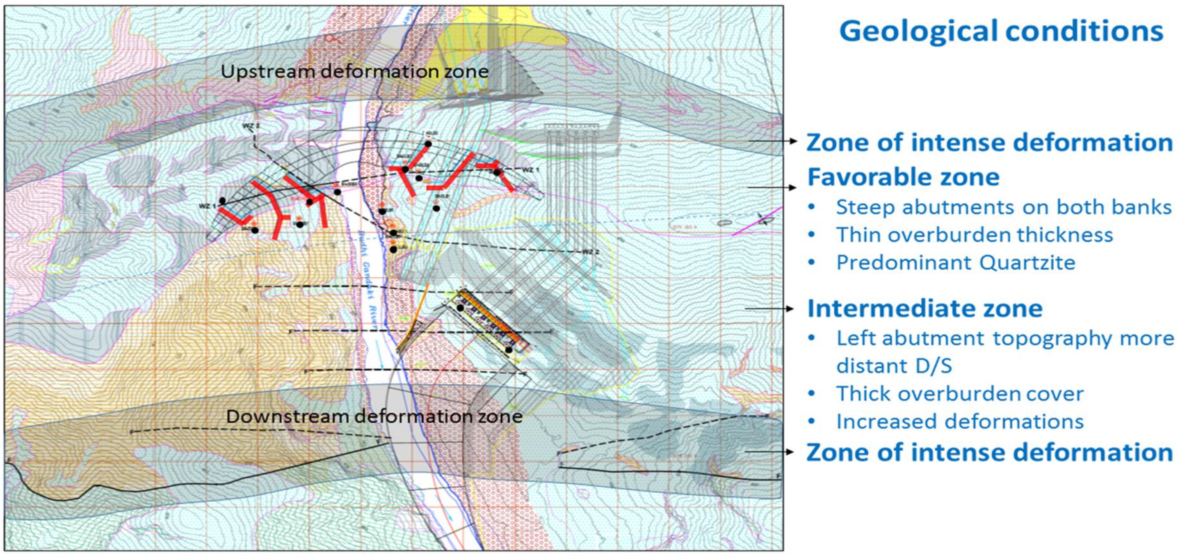


Figure 2-10: General geological conditions at project site

Two noticeable weakness zones, WZ1 and WZ2, continuous from one bank to the other, were highlighted by correlation of surface and underground data. These weak zones will require specific treatment but, owing to their orientation and steep dip, are not particularly unfavorable for the stability of the dam foundation.

One of the discontinuity sets identified at the dam site, including shears, features low dip to the SW. This attitude is unfavorable for the stability of the Left Abutment. The amplitude of the potential instability depends on the persistence of these discontinuities, which is difficult to apprehend precisely at the present stage (it will appear clearly when the excavations will have been performed). The unfavorable discontinuities were dully identified in the exploratory galleries, in particular in the GLM and GLL galleries. Their strength characteristics at various scales were evaluated based on field observations and strength tests of the sheared infill. Finally, potential failure scenarios involving these discontinuities have been considered for stability calculations according to “Londe wedge” method. The analysis performed for pseudostatic conditions corresponding to the design earthquakes, OBE and SEE, and with an estimation of wedge displacements made with the Newmark approach concluded that the wedge stability is not critical.

In the Right Bank, no evidence or indication for large scale instability were found so far.

In the Left Bank, former slope instabilities are inferred from the morphological pattern, considerable thickness of the overburden and the presence of open discontinuities in the upper part of the dam abutment.

Although no evidence was found for imminent risk of large instability, the landslide hazard will have to be reassessed during the opening of the excavations.

In the light of the findings in particular in the investigation adits, the average depth of excavations for the dam is estimated around 20 m. It could reach locally 25 m, and even 35 m in the upper part of the left abutment but could be only 10 to 15 m near the river bed.

Consolidation grouting, which could reach a depth of 15 m, should be systematic over the entire dam footprint.

The water pressure tests showed that the permeability decreased visibly below 40 m depth, but some intervals yielded 5-10 LU even at depth of 100 m. Taking into account these results, but also the height of the dam and the high seismic hazard, the preliminary design of the grout curtain contemplates a depth of 150 m in the central section, reduced to 100 m in the upper part of the abutments.

The amount of concrete needed for the currently studied double curvature arch dam alternative is estimated at 5.84 Mm^3. Two types of sources of construction materials have been investigated: the alluvial materials and rocks from quarry. Some rocks from the excavations could also be envisaged as an additional potential source.

The alluvial materials were found to be heterogeneous, both as lithology and particle size distribution. The potential amount of alluvial materials suitable for concrete has been estimated with various field investigations including a seismic refraction campaign carried out in 2015 in the reservoir footprint in Darbung VDC. The total volume of sand and gravel is estimated around 56 Mm^3. One of the main drawbacks of these materials is their potential for alkali-silica reaction highlighted by the preliminary tests. The preliminary study of potential sources for suitable binder system, inhibitory for the alkali-silica reaction, has been carried out and has shown that slag issued from iron furnaces in India could be used as raw cement material and that the cost of cement resulting from that process will not be higher than the one prevailing in Nepal.

The potential quartzite quarry located upstream of the dam site in the Left Bank of the Budhi Gandaki River is not recommended for further consideration, owing to difficult and costly extraction conditions. The dolomite potential quarry on the left bank above the Kalleri village, and downstream of the powerhouse complex has also been studied and also found suitable for concrete production subject to alkali reactivity inhibition with appropriate sourcing of cement material as suggested above. The suitability of the rocks extracted from dam excavations will also be assessed at the time of construction.

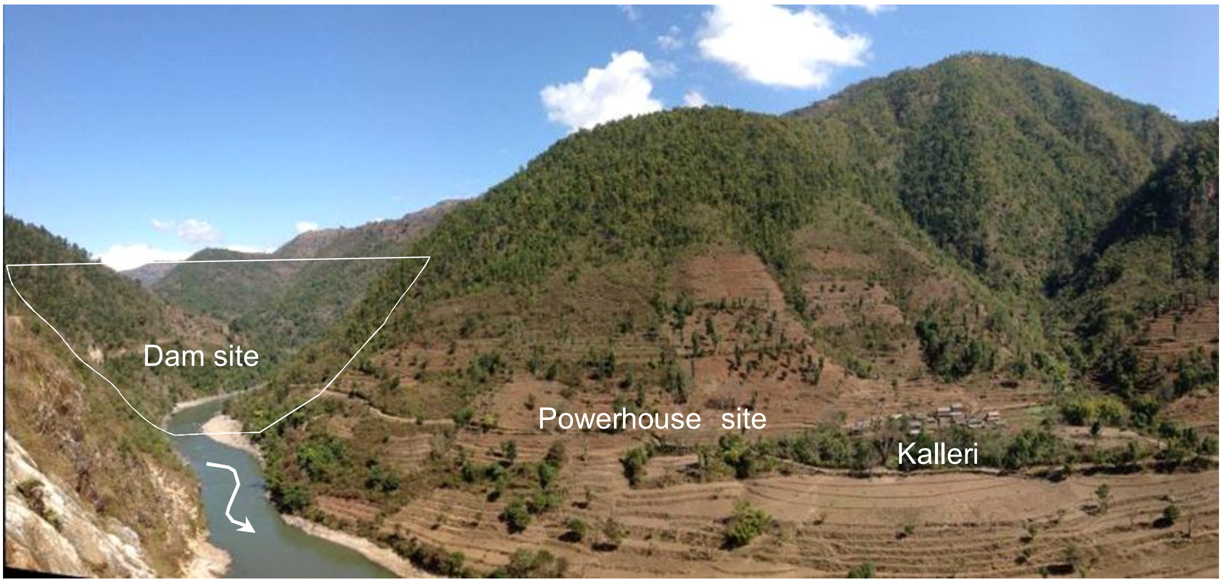


Figure 2-11: General view of Project site

2.5. Seismic hazard

The Himalayan chain (Figure 2-13), and consequently the Main Himalayan Thrust, is segmented by transverse NE-SW features. A 500 to 800 km long segment, the "central Himalayan seismic gap", between the epicentres of the great 1934 Nepal-Bihar (to the east) and the 1905 Kangra (to the west) earthquakes has not experienced a major quake above Mw 8.0 for more than 500 years (Figure 2-12). The Budhi Gandaki dam project falls in this region of possible future great earthquakes. Despite the present-day aseismic characteristic, the last major earthquake in the "central Himalayan seismic gap" of Mw 8.2 occurred 508 years ago, in 1505, and strongly damaged the region.

Since, few intermittent earthquakes including the two devastating earthquakes that occurred in northern Nepal on April 25th, and May 12th, 2015[2] have rocked the region and released limited parts of energy stored elastically due to the movement of the Indian plate. Still a large amount of residual stress has to be released by an earthquake of magnitude, possibly not less than 8.5, with a rupture likely located along the Main Himalayan Thrust at ~16 km depth, ~20km to the north of the dam.

Therefore the Deterministic Seismic Hazard Assessment has concluded the following horizontal accelerations to be taken into account in the design of the project structures:

- Operating Basis Earthquake (OBE): 0.6g
- Safety Evaluation Earthquake (SEE): 1.2g [3]

[2] *The devastating earthquakes with Mw 7.8 and 7.3 that occurred respectively on April 25, and May 12, 2015 in northern Nepal are not modifying the conclusions of the study. The Peak Ground Acceleration (PGA) of the Mw 7.8 earthquake was measured at 0.16g which is significantly lower than the PGA=0.6g corresponding to OBE adopted for the design of the Project, the verification of the Dam stability being made for the SEE with a PGA of 1.2g.*

[3] *According to the Bulletin N°72 rev 2010 of the International Commission on Large Dams (ICOLD) the* ***Safety Evaluation Earthquake – SEE*** *is the maximum level of ground motion for which the dam should be designed or analysed and for which damage to the dam, even extensive, may be acceptable as long as no catastrophic flooding occurs.*

Operating Basis Earthquake-OBE *is the level of ground motion at the dam site for which only minor damage is acceptable. The dam, appurtenant structures and equipment should remain functional and damage should be easily repairable.*

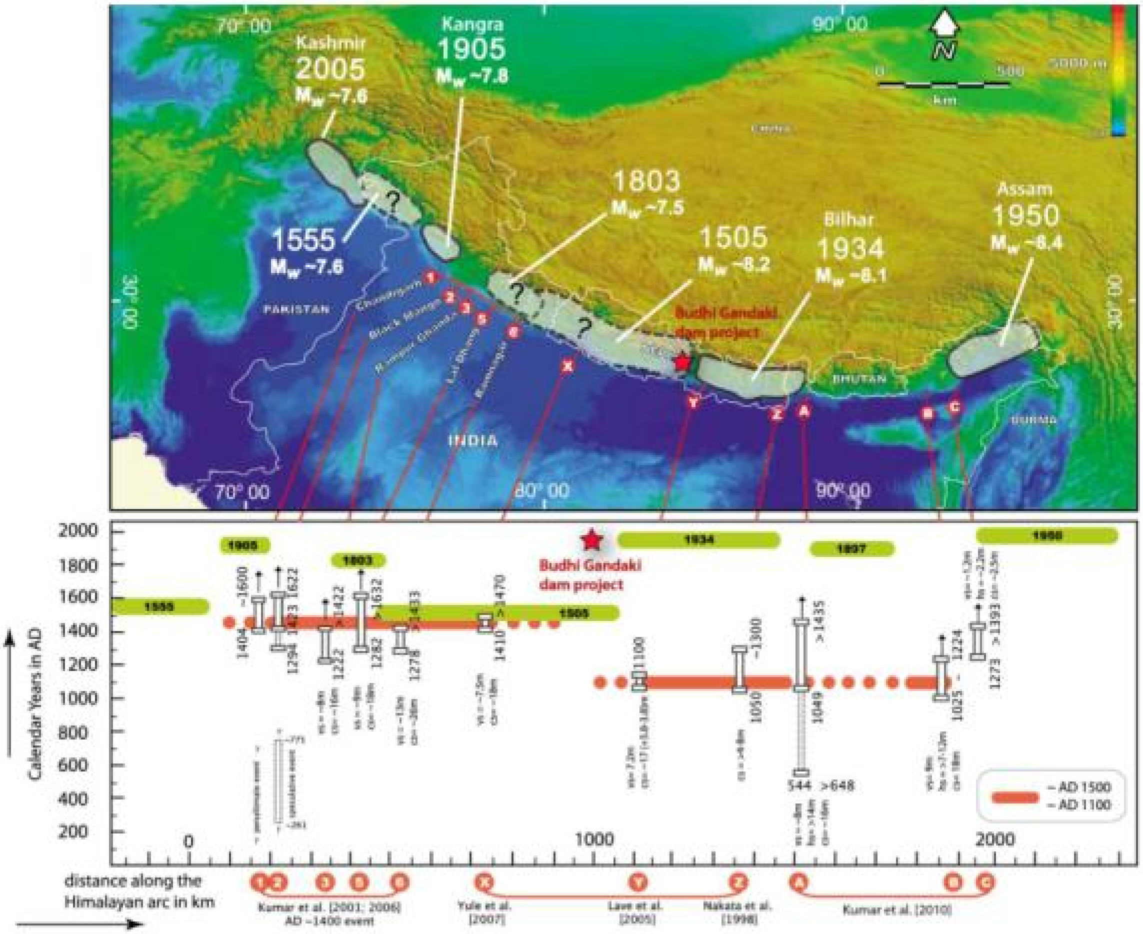


Figure 2-12: Synopsis of historical and paleoseismic history along the HFT (Kumar et al. 2010)

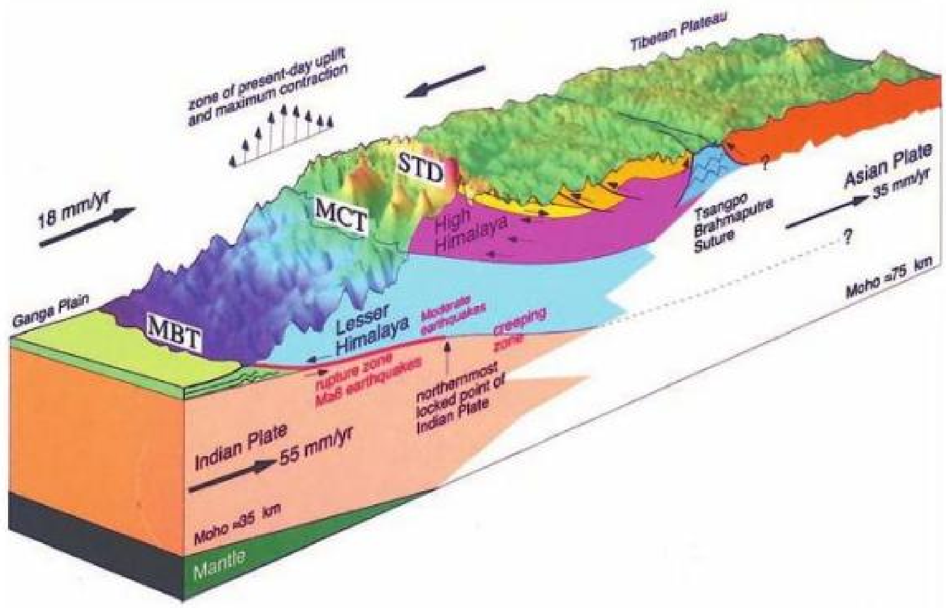


Figure 2-13: Block diagram illustrating the structures of the Himalaya (Searle 2013)

3. GENERAL LAYOUT, ACCESS AND FACILITIES

3.1. General layout

The double curvature arch dam is located on the Budhi Gandaki River, roughly 2km upstream the confluence with the Trishuli River.

The 263m high double curvature arch dam, with a FSL at El. 540, MWL and dam crest at EL. 542 , with a crest length of 760m incorporate the six sluices spillway, the two mid-level outlets and one low-level outlet.

A tailwater dam will also be constructed 300m downstream to the dam toe, with a sill at El. 330, to prevent the immediate dam downstream toe from erosion due to the spillway operation.

The six power intakes are located on the left bank of the reservoir and convey the water to the six units of the 1200MW capacity powerhouse. The six waterways, from the power intake to the powerhouse are between 787 m long (Unit 1) and 695 m long (Unit 6).

The potyard is located on the left side platform at El. 342.

The temporary river diversion works include:

- Two concrete lined 12m diameter diversion tunnels, excavated in the left bank, at El. 327 to 326,
- One upstream rockfill cofferdam with a crest at El. 357,
- One downstream rockfill cofferdam with a crest at El. 332.

The general layout is illustrated on the following **Figure 3-1**, **Figure 3-2** and **Figure 3-3**.

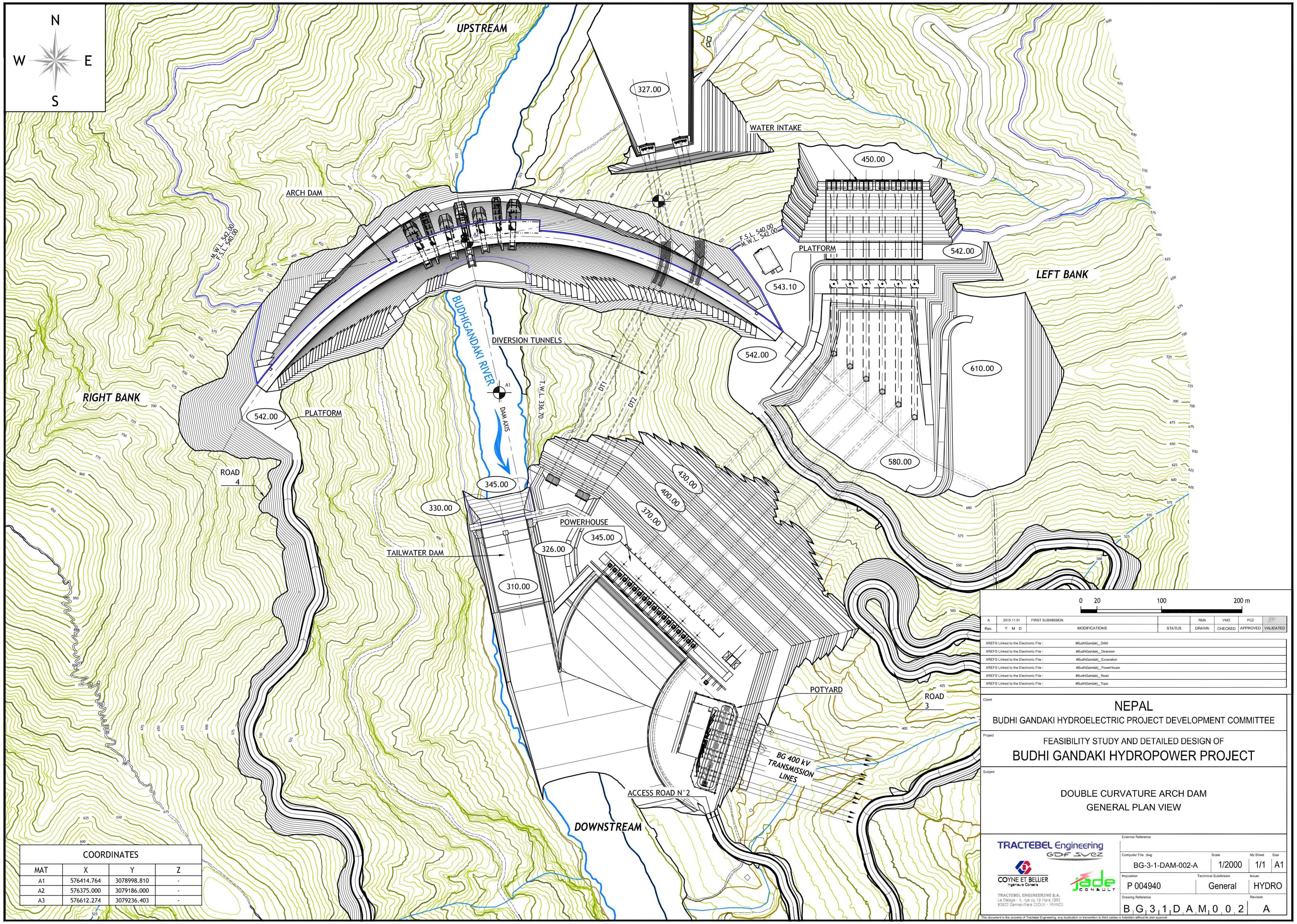


Figure 3-1: General Layout

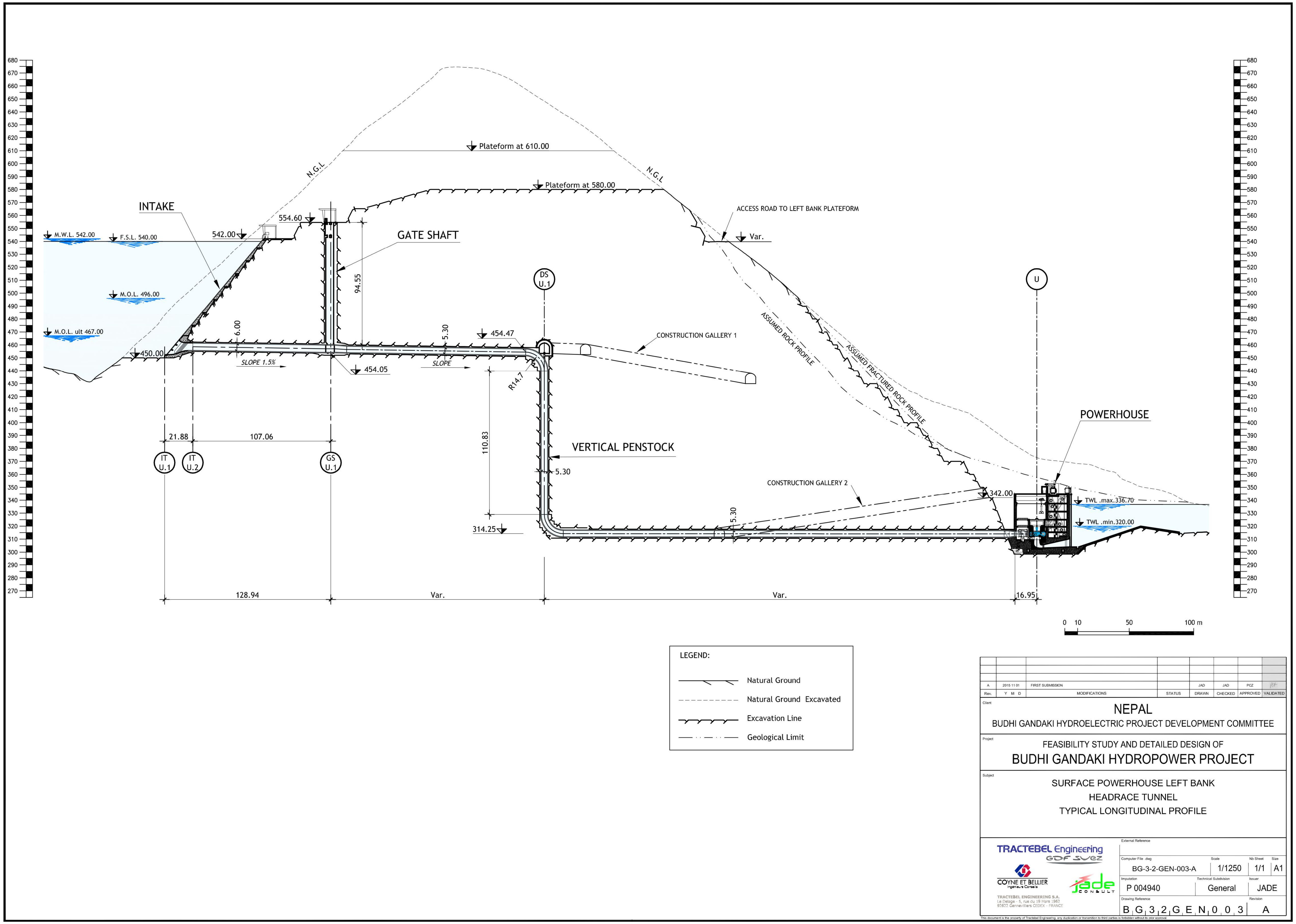


Figure 3-2: Waterway along Unit 1 – Longitudinal Profil

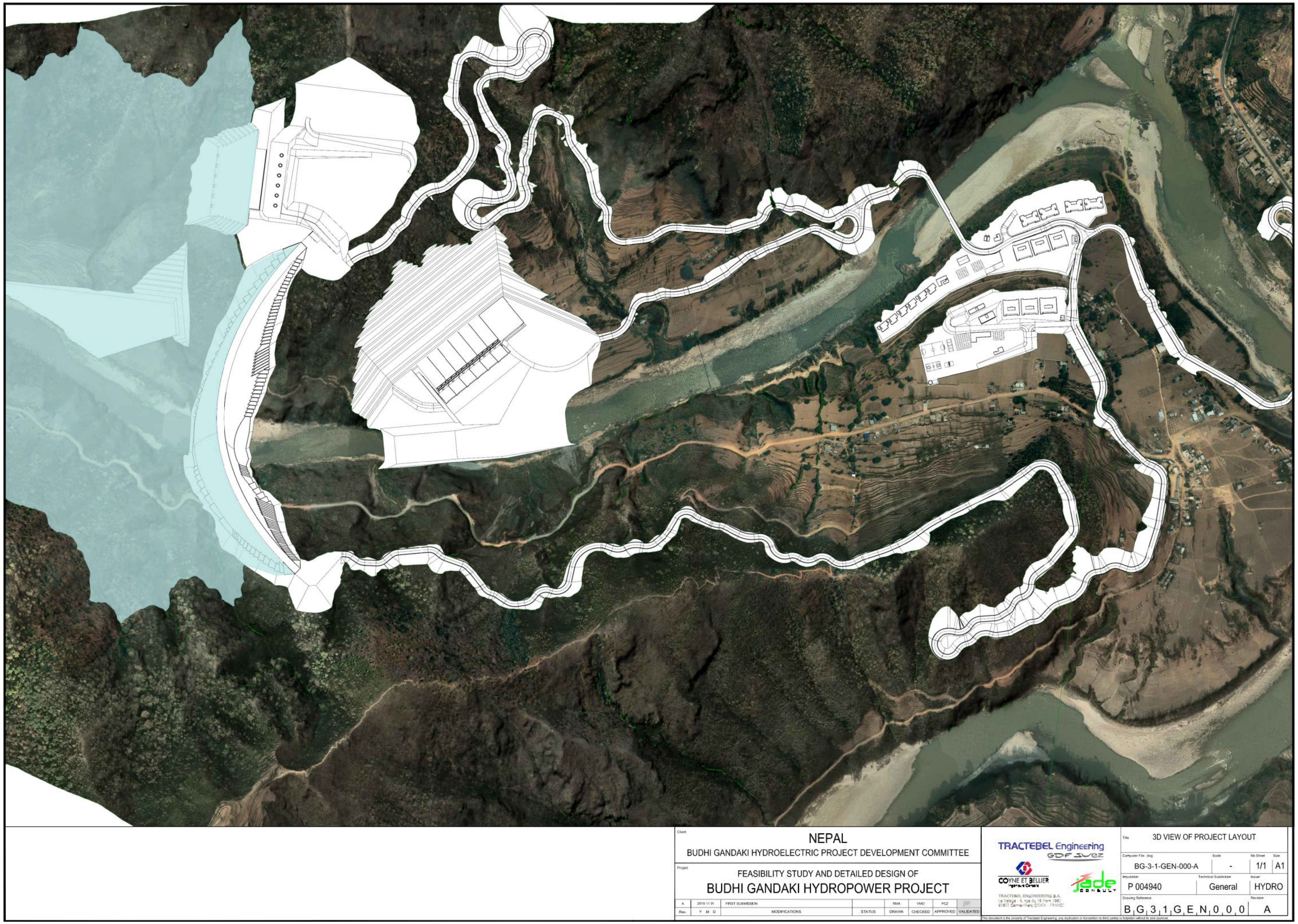


Figure 3-3: General Layout on LiDAR Orthophoto

3.2. Access roads to project permanent structures

Four roads are foreseen to ensure the access to the permanent structures and camps, with a total length of 8.16km, the detail and location are described in the **Table 3-1** below and in **Figure 3-5**:

S.N.	From	To	Length m
1	Prithvi Rajmarg (Highway)	Surenitar	**1110**
2	Surenitar	Powerhouse area	**1160**
3	Bridge	Dam Crest (Left Bank)	**2530**
4	Surenitar	Dam Crest (Right bank)	**3360**
	Total Length		**8 160**

Table 3-1: Location and length of permanent access roads

3.3. Permanent Bridge

A permanent bridge is foreseen across the Budhi Gandaki River roughly 1km downstream the dam location, to ensure the transit between right bank (contractor's camp and permanent camp) and the left bank (powerhouse and potyard location). Roughly 125 meters long with deck level at El.340 masl and a width of 9.5m, the bridge will be constructed in reinforced concrete.

3.4. Camps and facilities

Several platforms are foreseen for the purpose of the permanent Owner's Camp, the contractor camp and the construction facilities areas:

- Platform at El. 330m: Contractor's Camp, on the left bank,
- Platform at El. 340m: Permanent Owner's Camp, right bank between El.345 & 390
- Platforms at El. 542, 580, 610m: Construction platforms, left bank,

The preparatory works are detailed in the **Volume 14 – Design of the Preparatory Works**, they will be part of the LOT n°1 (Ref to Volume 15 Section 5.8 for the recommended subdivision of the works in different Lots) and required before the start of construction of the other LOT n°2 (Dam and appurtenant works) and LOT n°3 (complete Power component).

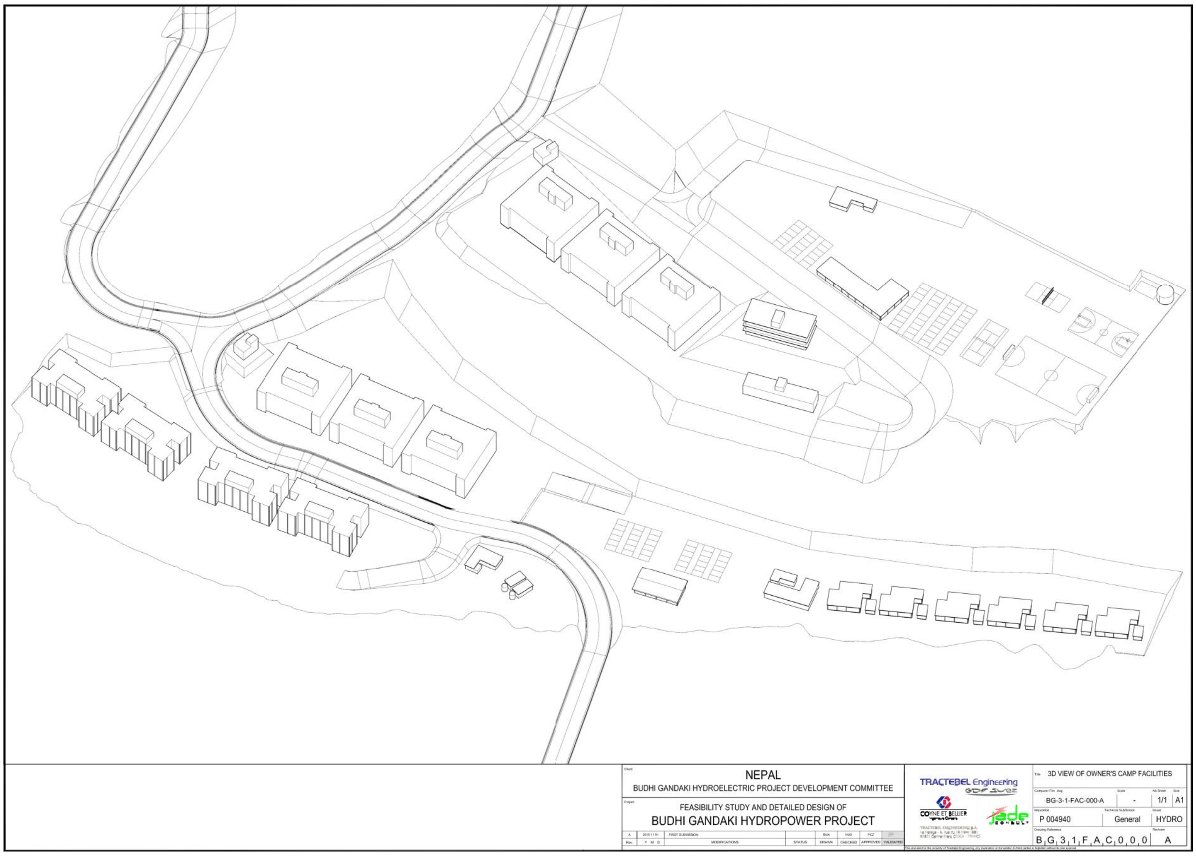


Figure 3-4: Permanent Owner's Camp in Surenitar

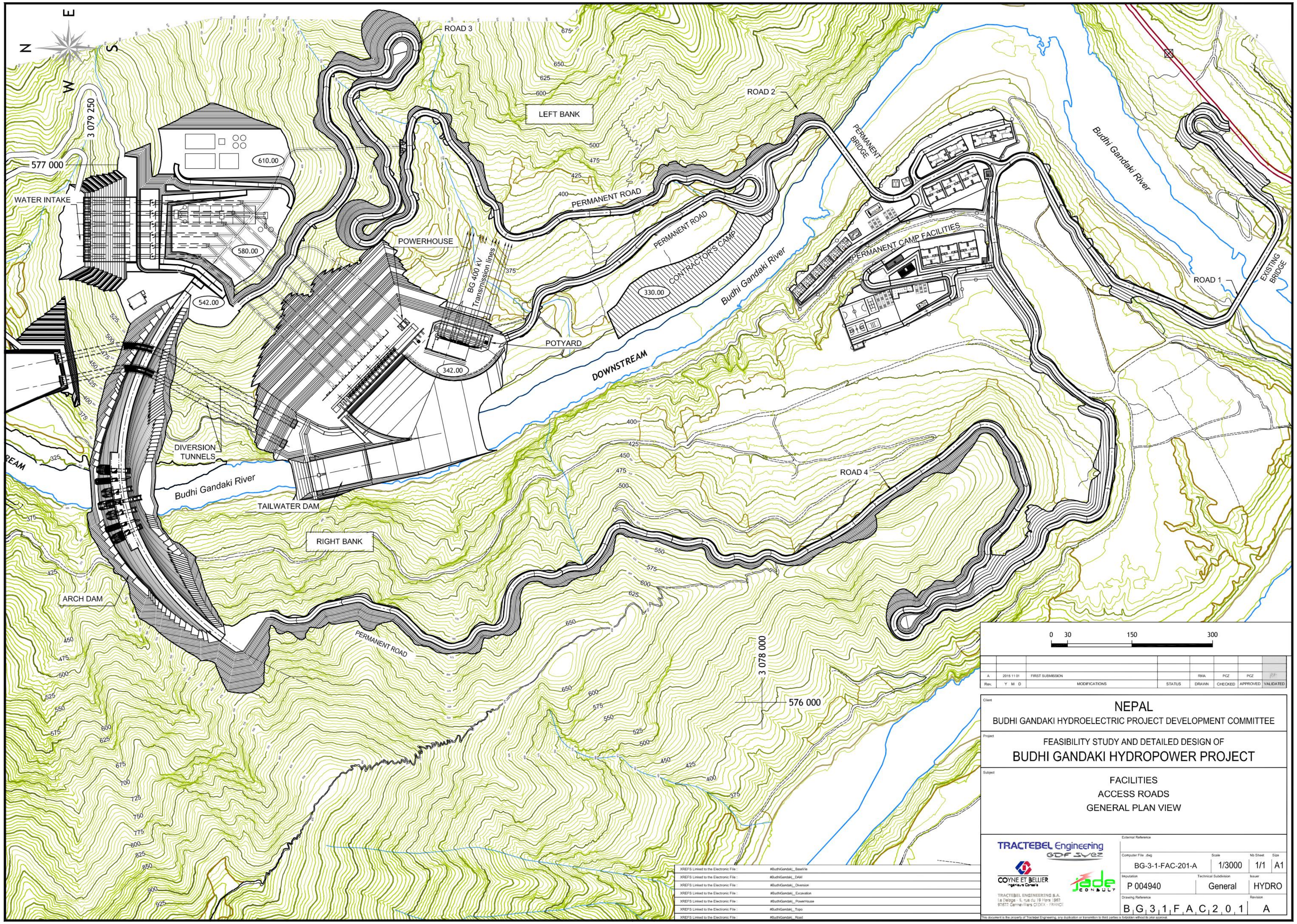


Figure 3-5: Access Roads and Facilities – General plan view

4. RESERVOIR CHARACTERISTICS AND RESERVOIR OPERATION STUDIES

4.1. Reservoir characteristics

The salient features of the reservoir are illustrated in the Figure 4-1 and Figure 4-2

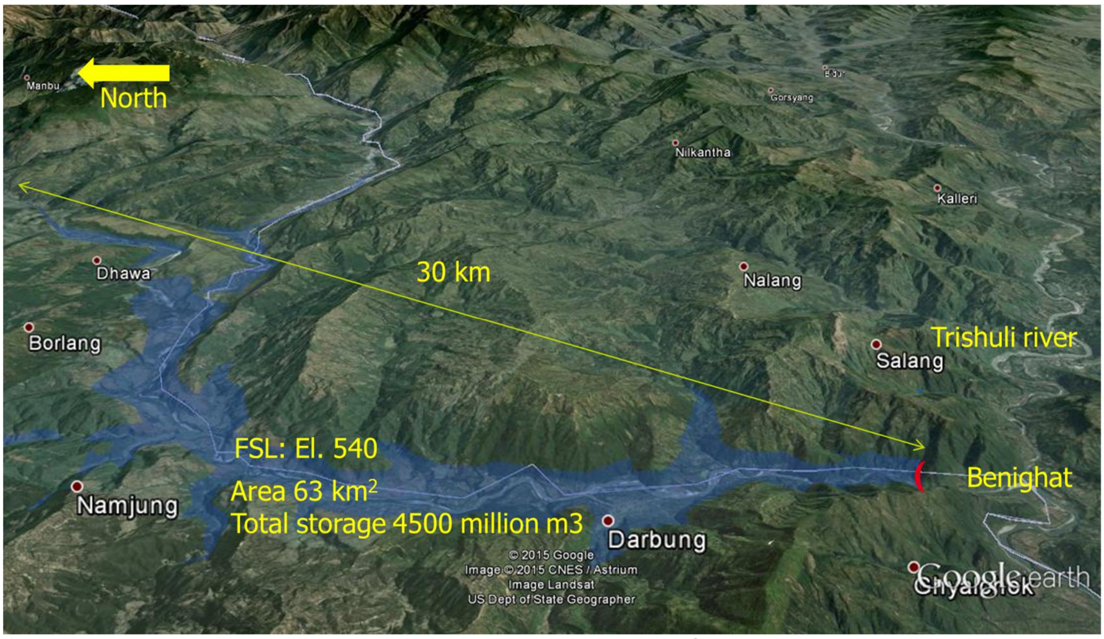


Figure 4-1: Main characteristics of the reservoir

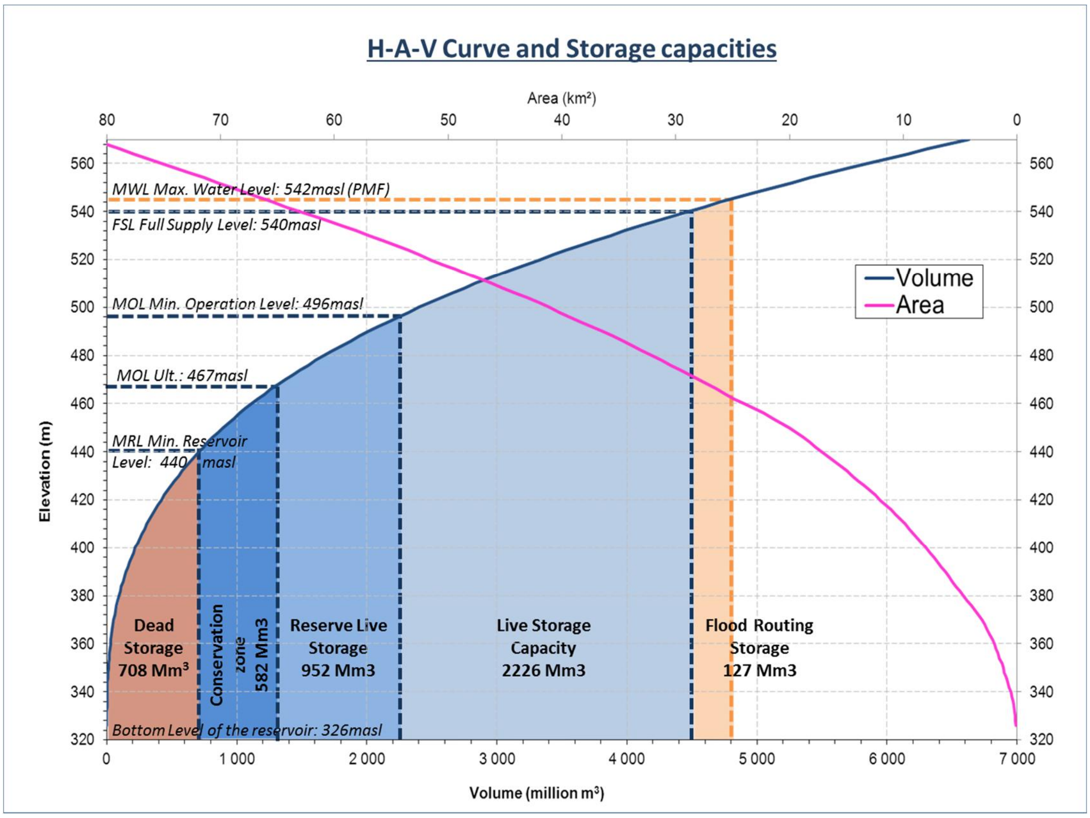


Figure 4-2: Reservoir area-volume curves and storage

The **Figure 4-3** below illustrates a schematic longitudinal section along the reservoir. The various levels operated by the power intake correspond to different water storages dedicated for specific purposes as described below.

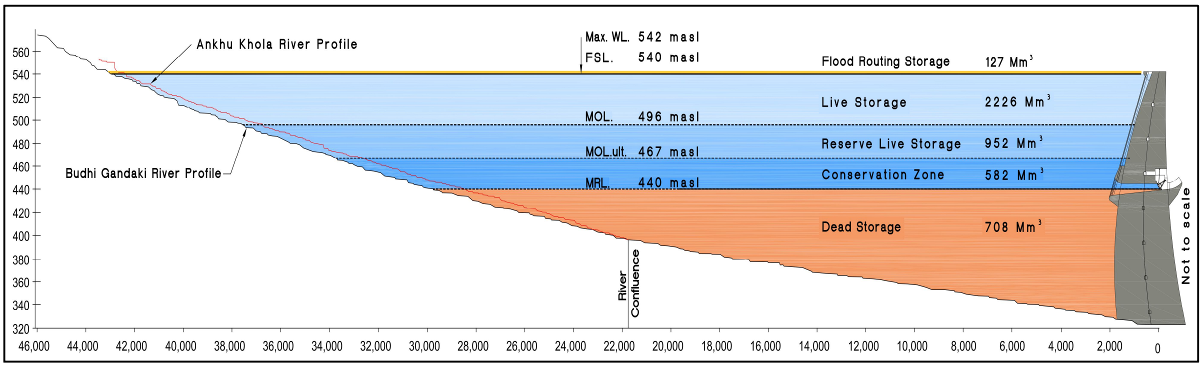


Figure 4-3: Reservoir characteristic levels

- **Dead Storage**: This storage extends from the bottom of the reservoir (El.326masl) up to the MRL (Minimum Reservoir Level) defined by the elevation of the MLO (El.440masl). Below this minimum elevation of gate operation, the water volume stored is lost. This dead storage of 708 Mm^3 will store progressively the fine sediments accumulated in the reservoir. Reference is made to Volume 2D n° BG-DDR-Vol2D for the sedimentation study.
- **Conservation Zone**: water storage between the MRL and the Ultimate MOL (El.467masl). This water storage cannot be used for energy generation since this will be outside the turbine range of operation. However, it is considered that in the far future, the issue of water availability (for irrigation and population water supply) could become more critical than the energy generation. In addition on the long term, with the climate change and the glacier melting, the hydrology of the Budhi Gandaki might present modified hydrological cycles with extreme drought and monsoon floods requiring appropriate regulation by the Budhi Gandaki reservoir Therefore this Conservative Zone provides another potential water volume of 582Mm^3..
- **Reserve Live Storage**: corresponds to the water stored between the MOL Ult. And the MOL (El.496masl). The MOL is the optimized reservoir elevation for the purpose of the winter peak energy generation. Nevertheless, it is assumed that in the middle term future, the purpose of BG HPP could evolve from a peak power project to a mixed peak power and base power plant. In this case, the project purpose could be to maximize the mean winter energy in decreasing the peak energy performances. Therefore this storage of 952 Mm^3 will provide flexibility in the future reservoir management.
- **Live Storage Capacity**: this storage of 2226 Mm^3 corresponds to the water accumulated between the MOL El.496masl nd the FSL El.540masl. It corresponds to the optimum volume to be used for the usual operation of the reservoir for the peak energy generation purpose and to ensure the complete filling of the reservoir for the following year.
- **Flood Routing Storage**: The MWL is the highest level the water can reach in the reservoir considering the routing of the floods in the reservoir while the downstream flood release is controlled by the spillway conditions. With the PMF entering in the reservoir and assuming that one sluice of the spillway would not be available the MWL comes to El.542.40 (the dam crest is at El.542 and crest parapet at El.543.1). If the combination of PMF and GLOF is considered and all the 6 spillway sluices are in operation the MWL comes to El.541.60. The 127 Mm^3 flood routing storage is therefore used occasionally for large flood volume storage and routing.

The **Table 4-1** below summarizes the main characteristics of the reservoir storages.

	Lower Elevation	Upper Elevation	Volume		Use	
	Masl	Masl	Mm^3	%	Frequency	Purpose
Dead Storage	326	440	708	**15**	**X**	The volume is lost, the gates cannot be operated below the elevation 440masl
Conservative zone	440	467	582	**13**	**Exceptional**	This volume cannot be used for energy production purpose but it is available is case of exceptional need of water
Reservoir Live Storage	467	496	952	**21**	**Flexible**	This volume can be used for energy generation as per the choice of power plant operation modality
Live Storage capacity	496	540	2226	**48**	**Usual**	Regular volume to fit the aim of BG HPP and the ensure the filling of the reservoir
Flood Routing storage	540	542	127	**3**	**Exceptional**	Extreme case for exceptional floods and spillway configurations
Total			**4595**	**100**		

Table 4-1 : Reservoir characteristic levels, storage capacities and functions

4.2. Optimization of the installed capacity and power generation

The main purposes of the reservoir operation simulations carried out over the period (1964-2012) were (i) to estimate the production and economic benefit of the system under varying hydrological conditions and (ii) to determine the mode (seasonality and peak production) of power generation for various power installed capacities (3 to 6 units of 200 MW each).

First the seasonal regime of the reservoir level variations was assessed. It is the result of the winter energy maximization (from mid-December to mid-May). The daily energy associated with a 95% exceedance probability over this period is 9.6 GWh. It does not depend on the installed capacity.

Then the mode of peak power generation was determined. It mostly depends on the number of power units. Overall, the increase in unit numbers results in power peaks more intense but of less duration.

- For 3 units the average monthly winter peak capacity is in the range 482 MW – 600 MW and the peak duration is in the range 16h – 18h.
- For 6 units the average monthly winter peak capacity is in the range 934 MW – 1,200 MW and the peak duration is in the range 8h – 9h.

The impact of the installed power upgrade on the spillage losses is moderate as the mean annual energy increases by only 6% from 3 to 6 units.

The mean monthly peak duration and peak capacity over the simulation period (1964-2012) are documented in T able 4-2. The mean daily energy generation is calculated and documented in Table 4-3 below.

Mean (1964-2012)	3 units		4 units		5 units		6 units	
	Peak Duration (h)	Peak Capacity (MW)	Peak Duration (h)	Peak Capacity (MW)	Peak Duration (h)	Peak Capacity (MW)	Peak Duration (h)	Peak Capacity (MW)
Mid-Dec to mid-Jan	16	600	12	800	10	1000	8	1200
Mid-Jan to mid-Feb	16	598	12	797	10	996	8	1195
Mid-Feb to mid-March	17	568	13	758	10	947	8	1137
Mid-March to mid-Apr	18	525	14	700	11	875	9	1050
Mid-Apr to mid-May	17	482	13	640	10	791	9	934
Mid-May to mid-June	14	470	10	624	8	775	7	918
Mid-June to mid-July	17	494	13	658	10	823	9	988
Mid-July to mid-Aug	16	566	12	755	10	944	8	1132
Mid-Aug to mid-Sep	19	598	17	798	16	997	14	1197
Mid-Sep to mid-Oct	19	559	16	745	13	931	11	1117
Mid-Oct to mid-Nov	11	600	8	799	7	994	6	1173
Mid-Nov to mid-Dec	6	599	5	775	4	879	4	928

Table 4-2 : Mean monthly peak duration and capacity over the simulation period

Mean (1964-2012)	3 units	4 units	5 units	6 units
	Daily Energy (GWh/day)	Daily Energy (GWh/day)	Daily Energy (GWh/day)	Daily Energy (GWh/day)
Mid-Dec to mid-Jan	9.6	9.6	9.6	9.6
Mid-Jan to mid-Feb	9.6	9.6	9.6	9.6
Mid-Feb to mid-March	9.5	9.5	9.5	9.5
Mid-March to mid-Apr	9.5	9.5	9.5	9.5
Mid-Apr to mid-May	8.1	8.1	8.1	8.0
Mid-May to mid-June	6.5	6.5	6.5	6.5
Mid-June to mid-July	8.5	8.5	8.5	8.5
Mid-July to mid-Aug	8.8	8.9	9.0	9.1
Mid-Aug to mid-Sep	11.5	13.8	15.5	16.4
Mid-Sep to mid-Oct	10.7	12.0	12.4	12.5
Mid-Oct to mid-Nov	6.7	6.7	6.7	6.7
Mid-Nov to mid-Dec	3.8	3.8	3.8	3.8
Mean winter Energy (GWh	1408	1408	1408	1408
Mean annual Energy (GWh)	3163	3276	3346	3383

Table 4-3 : Mean monthly daily energy generation over the simulation period

The **mean annual energy generated by BG HPP with 6 units is therefore 3383 GWh/year out of which 1408 GWh is produced during the winter period from mid-December to mid-May**.

This generation is referred in this report as **Generation Scenario 1** and is based on a conservative approach of the estimated river runoff at the dam site. The following section 4.4 presents a revised generation scenario based on updated river runoff estimates.

The annual energy produced along the simulation period 1964-2012 as a function of the installed capacity is represented on the Figure 4-4. It can be observed that the maximized winter energy is constant and independent from the installed capacity.

The spillage along the simulation period 1964-2012 as a function of the installed capacity is represented on the Figure 4-5. It can be observed that the spillage is significantly reduced with increase installed capacity. This is explained by the fact that the complete reservoir filling of the reservoir occurs generally between mid-August and mid-September. The large

river inflows are passed through the turbines up to the capacity of the power station. During this phase, the Budhi Gandaki HPP acts like a run of the river power station with constant level and all river discharges exceeding the maximal capacity of the power station are spilled.

One can conclude that the increase of the power station installed capacity (number of units) has two main impacts:

- First, it increases the mean annual generated energy. This would be the direct consequence of less spillage losses during the monsoon high flows period.
- Then, it increases the peak capacity for peak power generation throughout the year.

It is therefore recommended to install 6 units of 200 MW with a total rated discharge of 672m^3/sec.

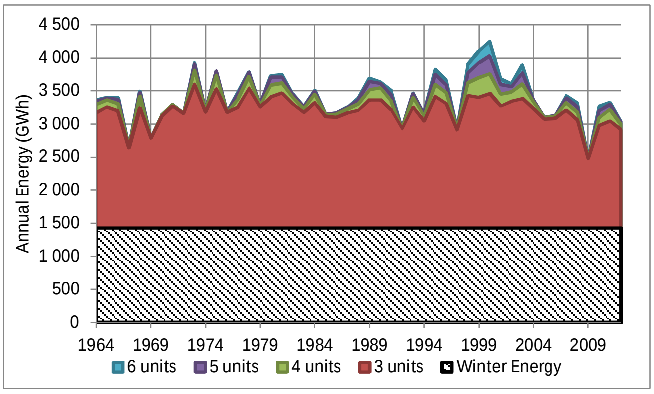


Figure 4-4: Annual energy and installed capacity

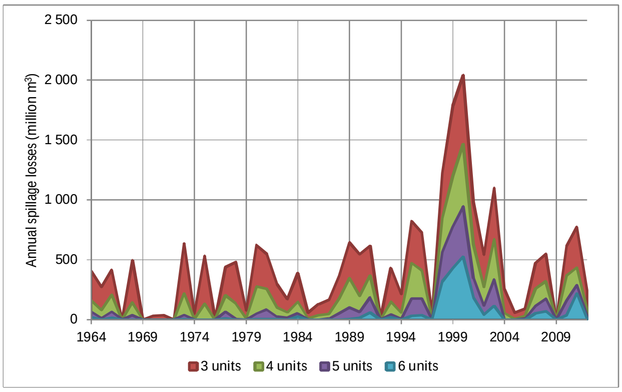


Figure 4-5: Spillage and installed capacity

4.3. Optimization of the Minimum Operating Level (MOL)

An optimization of the minimum operating level (MOL) has been conducted.

The Figure 4-6 and Figure 4-7 presented below illustrate that:

- The maximized winter energy does not depend on the number of units. It decreases with higher MOLs. Conversely, the energy generated in wet season decrease. This is the consequence of the enhanced reservoir capacity of regulation.
- The impact of the MOL on the annual energy differs with the number of units.

  For 3 units, the annual energy shows an optimum at MOL El.490 m. After that, the annual energy decreases due to higher spillage losses.

  For 6 units, the curve does not show any optimum. The rated discharge in this case (6 x 112 m^3/s) is large enough to keep the storage losses very low. The head is maintained at a high level so that the energy generation is maximized.

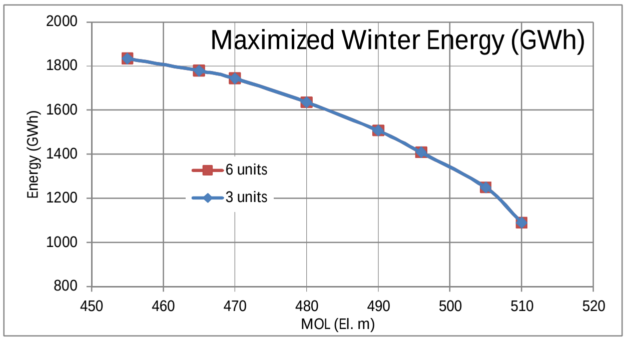


Figure 4-6: Winter energy for various MOLs

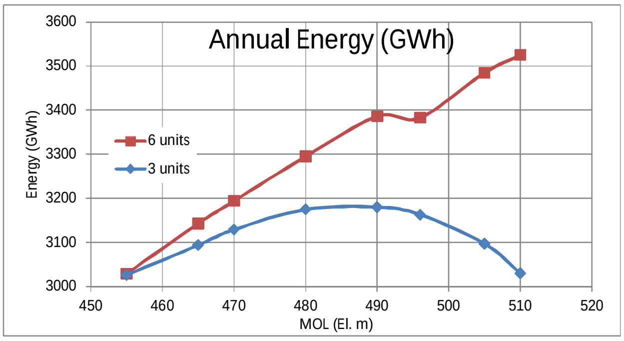


Figure 4-7: Annual energy for various MOLs

Yet it is worth mentioning that the increase in winter energy with lower MOLs is only due to the increase of the peak duration. The peak capacity decreases due to a lowered mean head.

Actually the mean peak capacity in winter is limited by the head available rather than by the volume of water available for hydropower.

In conclusion, a lower MOL would increase the overall winter energy. But the peak power generation performances would be significantly reduced. It would be similar to base power operation rather than peak power generation.

The MOL at El. 496 m is certainly the best choice because it offers a well suitable mode of power generation in winter with peak capacity of 930 to 1200 MW and peak duration of 8 to 9h in the case of 6 units.

4.4. Power generation review in view of increasing inflows

The most recent results of the river discharge monitoring (see also section 2.1) have confirmed that the adopted inflows series at dam site were evaluated with a conservative approach at the time of the phase 2: Feasibility Study. The latter does not affect any of the results from the reservoir operation studies regarding the optimization of the installed capacity or the minimum operation level.

Yet, an increase in the energy potential is expected from the review of inflows at the dam site. New simulation runs for the 6-units plant scheme were carried out to take into account the review of inflows. The main results are:

- the **daily energy** associated with a 95% exceedance probability **over the winter period** (mid-December to mid-May) is **10.8 GWh/day (+13%)**;
- the average monthly winter peak capacity is in the range 970 MW – 1,200 MW and the peak duration is in the range 9h – 10h;
- the **mean winter energy is 1,623 GWh (+15%)**;
- the **mean annual energy is 4,250 GWh (+26%)**;
- despite the increase in inflows the spillage losses remain very low, accounting on average for less than 2% of the inflows.

This generation scenario is referred in this report as **Generation Scenario 2.**

5. DESCRIPTION OF T HE WORKS – DAM AND APPURTENANT STRUCTURES

5.1. Double curvature arch dam

5.1.1. General and setting-out

The Dam is designed as a double curvature concrete arch dam, which has appeared during the Feasibility Stage to be t he most economical dam alternative, considering the topography and the geology of the site. The geometry of the dam is defined by logarithmic spirals. The dam setting out is governed by several factors inherent to the topography and to the geological conditions. It has been chosen to avoid the weak zones in the immediate upstream and downstream areas on both sides of the natural narrow stretch of the valley, and to lay the abutments on sound rock areas extending the excavation depth as required based on an extensive investigation campaign.

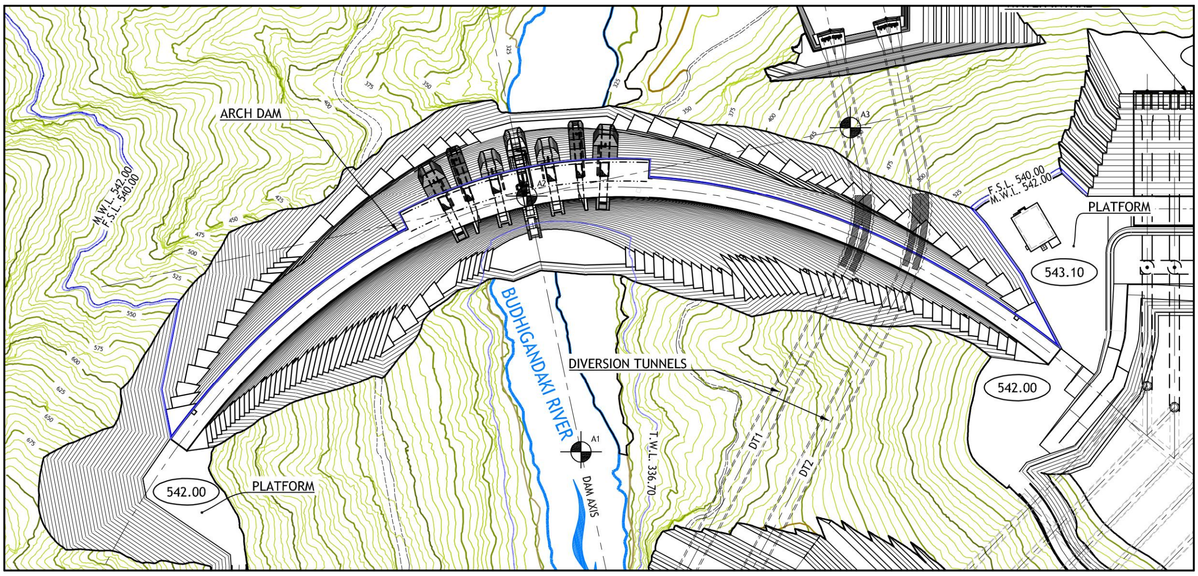


Figure 5-1 – General plan view of the dam.

5.1.2. General arrangement

8 levels of galleries have been positioned in the dam, for access, maintenance, and monitoring purposes. These galleries have also been extended into the foundation, in order to allow the execution of the grout curtain and to ensure a good drainage of the dam foundation downstream of the grout curtain.

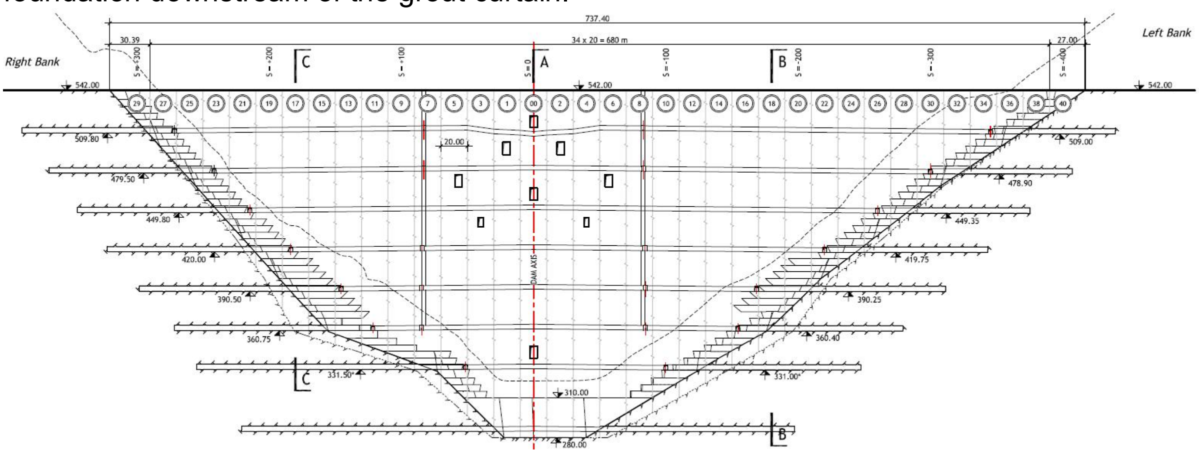


Figure 5-2: View in elevation of the dam and its galleries

All facilities for the flood control (during construction and operation stage) have been incorporated in the dam. Hereunder are presented three sections through the dam. One (on the left) presents three levels of hydraulic gates. The two other sections are more on the banks. On them can be seen the drainage tunnels of the inferior levels.

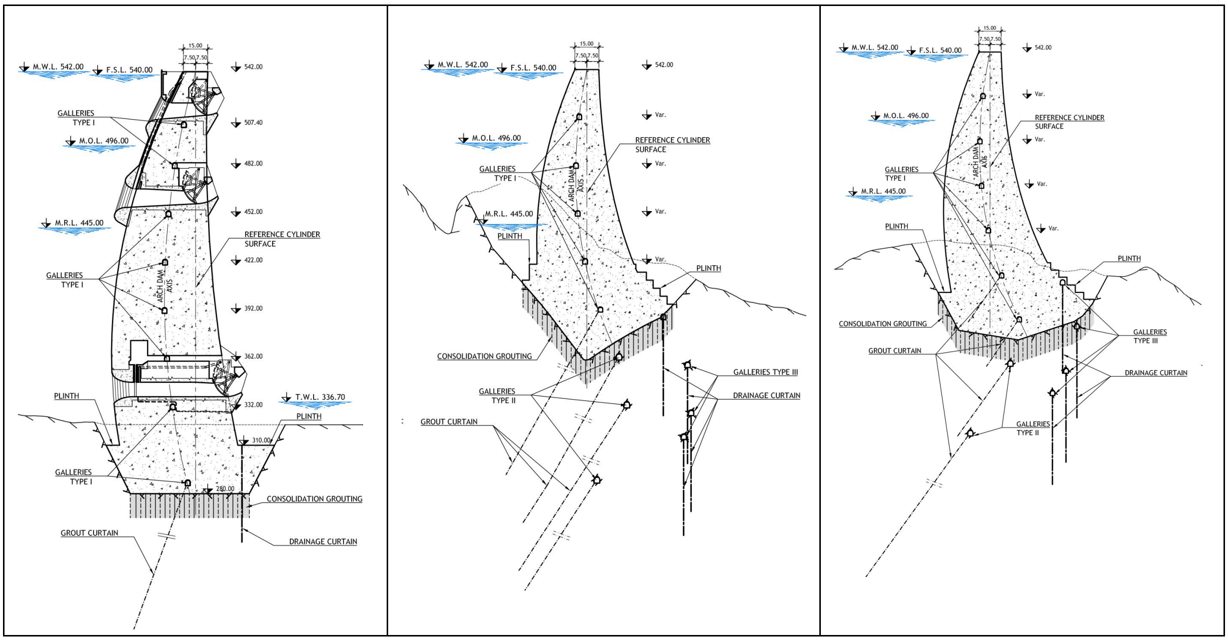


Figure 5-3: 3 Views of typical sections through the dam and its foundation

5.1.3. Dam calculations

This paragraph presents the dam calculations which were carried out for the Detailed Design Studies. These computations aim to make a comprehensive analysis of the double curvature arch dam structural behavior against static and dynamic solicitations.

This study is based on a 3D finite-elements model, elaborated with the calculation code COBEF, finite-elements software especially developed by COYNE ET BELLIER for dam analyses, and successfully implemented in numerous projects.

5.1.3.1. FEM Software

COBEF is a finite-elements computation code developed by COYNE ET BELLIER for the resolution of static/dynamic, bi-dimensional/three-dimensional problems with linear behaviors.

For this study, COBEF is used to perform:

- Static analysis carried out with a linear elastic model: to calculate the displacements and stresses for different loading cases (Empty reservoir, Minimum Operational level and Full supply level reservoir);
- Dynamic analysis: to calculate resonant frequencies, and carry out a spectral analysis in Fourier's domain based on accelerograms and to recombine a temporal solution for the displacements and stresses.

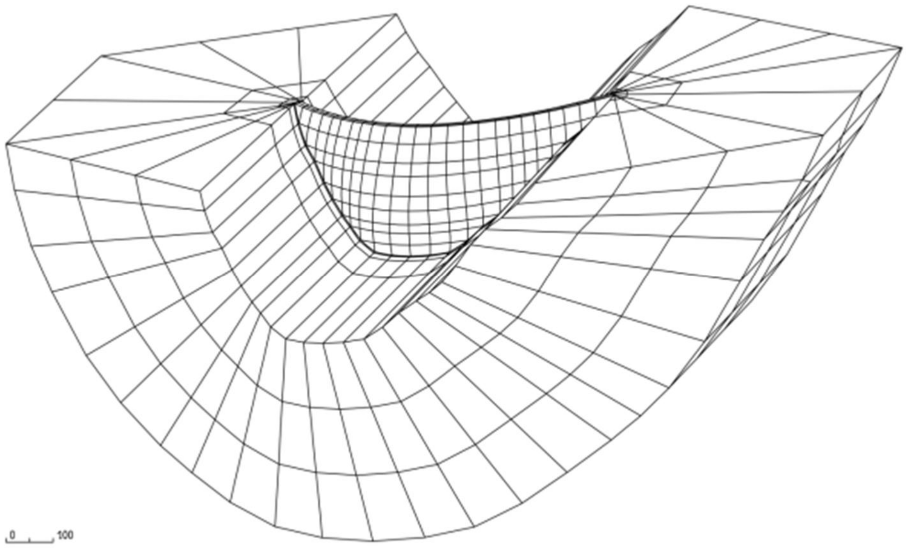
5.1.3.2. Geometry and Mesh

The model is composed of 6 449 nodes forming 1 406 elements, distributed as follow:

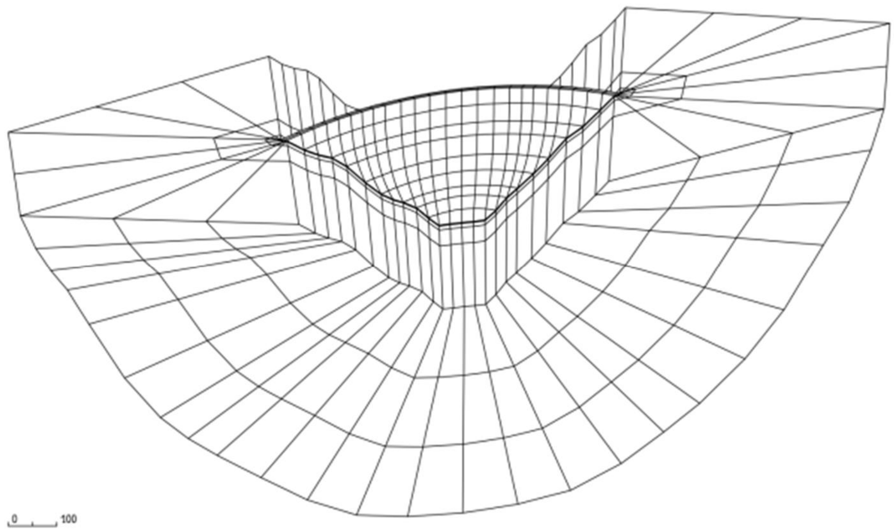
- 415 volume elements for the dam itself;
- 908 volume elements for the foundation;
- 83 joint elements at the dam/foundation contact.

The part of the mesh representing the dam is composed of i soparametric quadratic elements in height, 24 in the bank-to-bank direction, 9 in the elevation, and 4 from upstream to downstream.

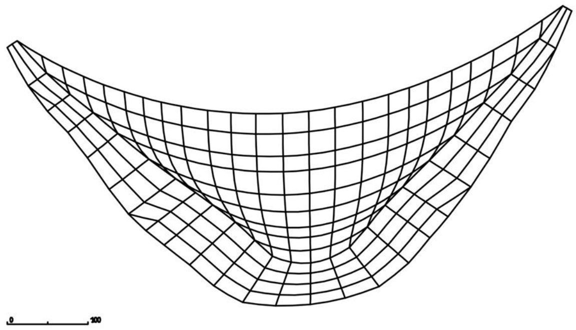
The foundation is m odelised with a sim plified shape. The distance between the dam footprint and the outside foundation boundary is large enough (equivalent to the dam height) to avoid boundary effects (see below
Figure 5-4).



1



2



3

Figure 5-4: 1/ Perspective view from upstream – 2/ Perspective view from downstream 3/ View from below – Dam foot print

5.1.3.3. Boundary conditions

All nodes at the outside limits of the foundation mass (upstream, lower and downstream) are fixed. All other nodes are free.

5.1.3.4. Characteristics of materials

The characteristics of the concrete dam and the rock foundation as assumed in the calculations are presented in the table below.

Material	Static modulus [GPa]	Dynamic modulus [GPa]	Poisson coefficient [-]	Unit weight [KN/m^3]
Concrete	20	25	0,2	2.35
Rock	10	12.5	0,2	-

Table 5-1: Material characteristics

The material dynamic properties depend on solicitation velocity. In order to take into account the material dynamic behavior, the dynamic modulii are derived from static modulus values multiplied by a coefficient 1.25.

Different values of the dumping coefficient have been used. This coefficient is generally used in elastic models in order to indirectly take into account the non-linear effects that develop during shakes. Its value depends on the amount of such non-linear features, which itself depends on i) the type of structure, and ii) the level of dynamic loadings:

- Usual values for soil or rockfill are in the range of 10 to 20%,
- Usual values for microcraked concrete are between 4 and 7% depending on the load level assumed; however recent back analyses of dams having been submitted to an earthquake suggest that dumping values may be much higher: for example, in the case of Kurobe dam, this coefficient varies between 7.5 and 20% [4].

In the case of Budhi Gandaki, the dam height and the seismic level justify the adoption of such values. The following have been adopted:

- for OBE (0.6 g): A=10%;
- for SEE (1.2 g): A=20%.

The definitions of SEE (Safety Evaluation Earthquake) and OBE (Design Basic Earthquake) are reminded in following paragraphs.

5.1.4. Definition of Loads

5.1.4.1. Dead weight

Arch dams are built by blocks, and during construction stage, the blocks are free from each other (not connected). After they have been completed, concrete shrinkage and cooling, induce the opening of joints between blocks, as shown in the Figure 5-5. As blocks are working as independent elements, inner resulting stresses are vertical.

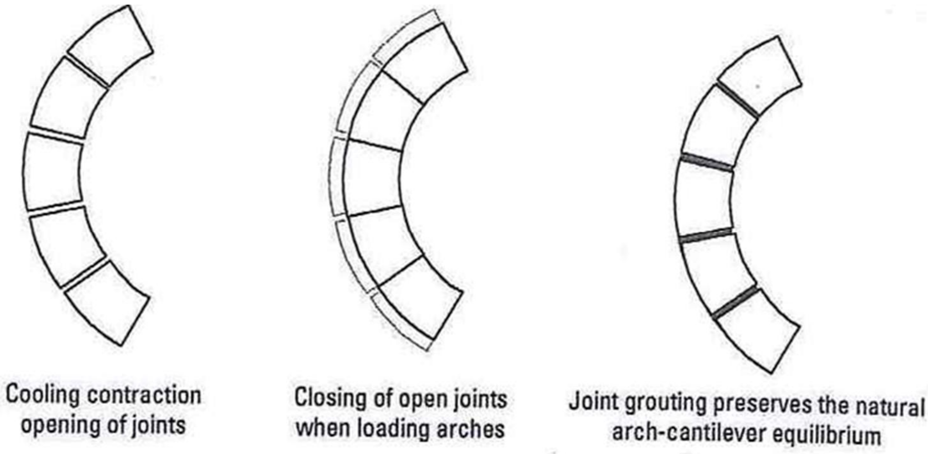


Figure 5-5: Cooling effect

This first step of the numerical analysis provides the initial stress state before the first impounding of the dam:

- Displacements induced by the un-grouted dead load case are set to zero since monitoring begins after the dam construction.
- Stresses are vertical and remain maximal at the upstream dam toe.

5.1.4.2. Hydrostatic loads

The water levels considered for static analysis are the followings:

- Empty reservoir,
- Full supply level: 540 masl,
- Minimum operational level: 467 masl.

The uplfit pressures are introduced in the joints at the contact of dam and foundation. A linear profile from upstream to downstream is considered.

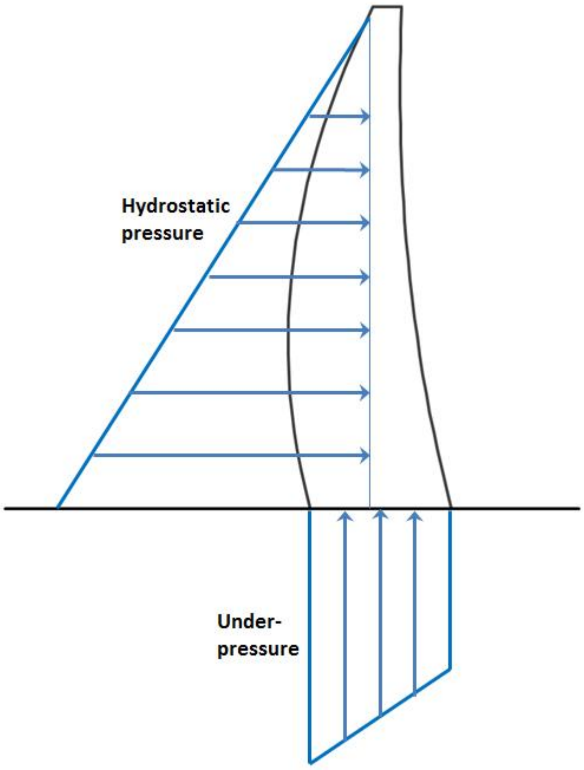


Figure 5-6: Hydrostatic pressure and under-pressure

5.1.4.3. Seismic loads

5.1.4.3.1. Accelerogram and spectrum

According to the bulletin N°72 of the ICOLD:

Two definitions of earthquake for which the dam should be designed or evaluated are recommended: Maximum Design Earthquake (MDE) and O perating Basis Earthquake (OBE). Both depend on the level of seismic hazard which is presented in Volume 3-Geotechnical, Geological and Seismic Hazard Analysis.

With the foregoing background, the earthquake levels for which the dam should be designed and analyzed should be as follows:

- **The Maximum Design Earthquake (MDE),** will produce the maximum level of ground motion for which the dam should be designed or analyzed.
- **The Design Basic Earthquake (OBE),** represents the level of ground motion at dam site at which only minor damage is acceptable.

According to bulletin N°148 of the ICOLD, the term SEE (**Safety Evaluation Earthquake)** has been introduced in t he second edition and replaces the term maximum design earthquake (MDE) used in the first edition.

At Budhi Gandaki dam site, the corresponding PGA (Peak Ground Acceleration) recommended for these two earthquakes solicitations in the above mentioned Volume 3 are the following:

- SEE: 1.2g,
- OBE: 0.61g.

In this framework, three accelerograms (Acc.1, Acc.2, Acc.3) are calibrated in order to represent, as much as possible, the design spectrum (see Figure 5-7).

These accelerograms are applied in the 3 directions:

- X direction : Bank to bank,
- Y direction : Upstream/downstream,
- Z direction : Vertical.

The most critical solicitation is in the downstream/upstream direction.

The following figure represents the spectrums corresponding to t he simulated accelerograms, and the design spectrum.

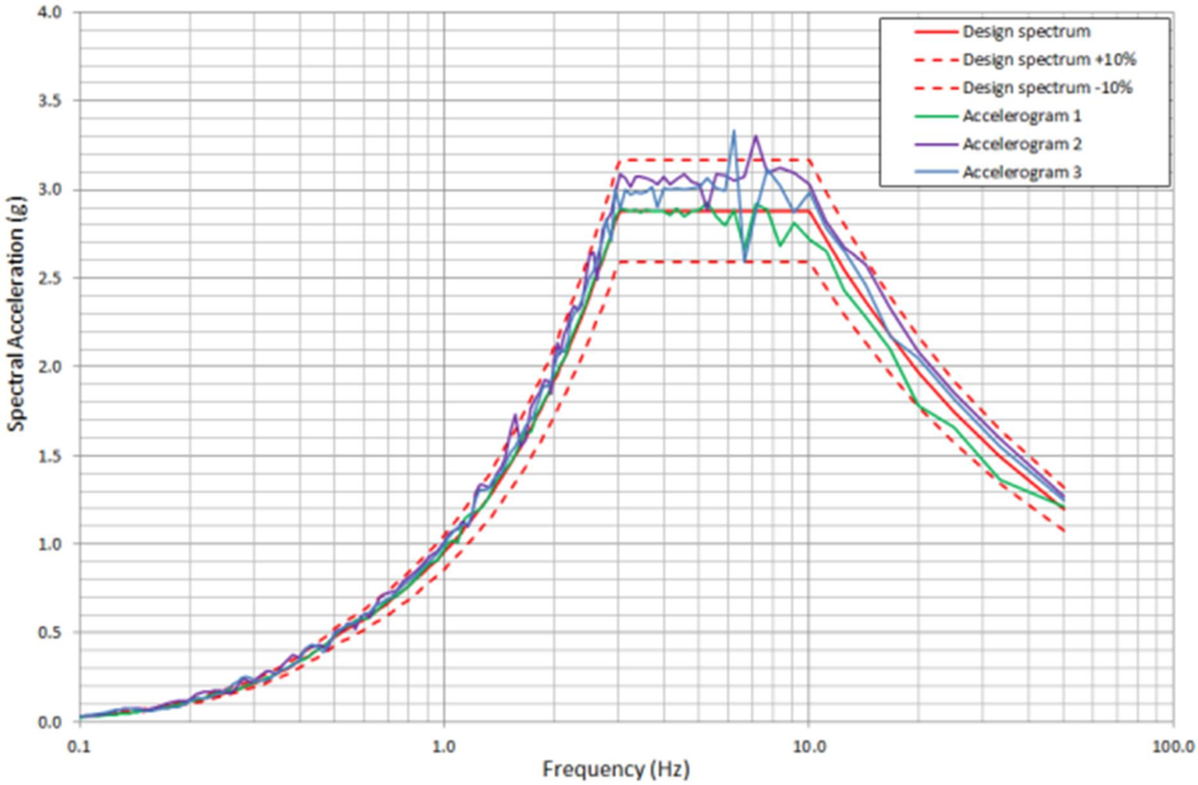


Figure 5-7: Design and simulated spectrums

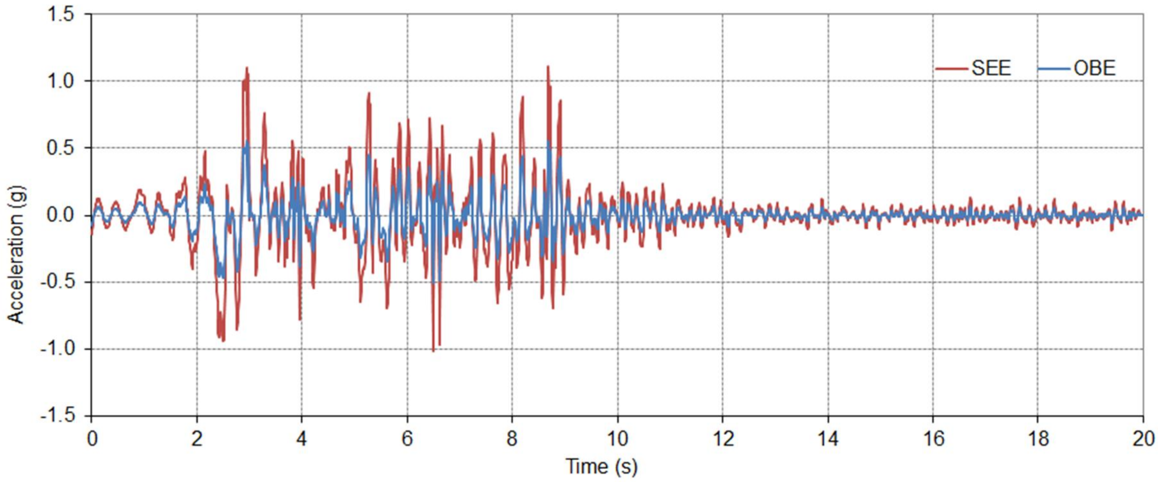


Figure 5-8: Accelerogram 1 – SEE and OBE

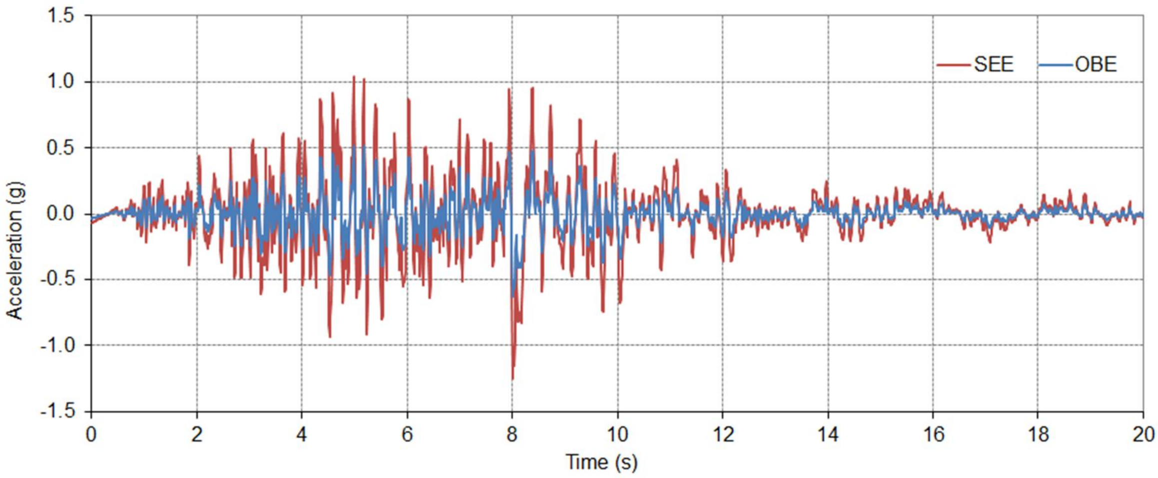


Figure 5-9: Accelerogram 2 – SEE and OBE

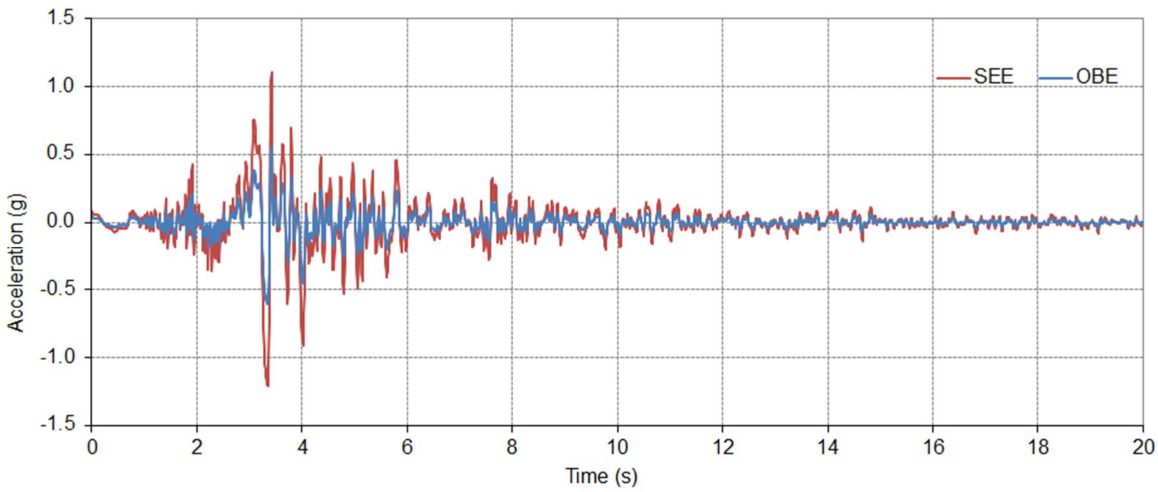


Figure 5-10: Accelerogram 3 – SEE and OBE

5.1.4.3.2. Hydrodynamic water pressure

When an earthquake occurs, the water reservoir is no longer still and applies a non-negligible hydrodynamic pressure on the dam's upstream face. Consequently the fluid interaction must be taken into account.

If the reservoir water is assumed to be incompressible, the hydrodynamic effect can be modeled by equivalent added masses of water on the upstream face of the dam. This body of water is attached to the dam and moves back and forth with the dam while the reservoir water remains still. Westergaard suggested the following shape for the mass of water:

$$m_{Ai} = \frac{7}{8}\rho\sqrt{H(H-z_i)}A_i$$

where:

-	H	[m]	Water depth,
-	ρ	[kg.m^{-3}]	Water mass per volume ratio,
-	z_i	[m]	Height above the base of the dam,
-	A_i	[m^2]	Nodal surface area.

A water mass has been allocated to each node, in upstream face of the dam, to take into account the water effect during the earthquake.

5.1.4.4. Other loads

Other types of loads generally taken into account for concrete dam analyses are: i) thermal loads, and ii) silt loads.

In the present case, thermal loads are negligible: due to the large dam thickness, the temperature inside the concrete body will be nearly constant, except close to the faces where temperature variations will be reduced and will produce only local minor stress changes. Thermal loads have therefore not been included in the analyses.

The effect of silt loads is confined to the lower part of the dam and has therefore a negligible influence on the global behavior of the structure.

5.1.5. Loads combinations

Static and dynamic loadings have been combined :

- Dead self-weight loading: for all combinations;
- Water level: empty, min. operating level 467 masl, and full reservoir level 540 masl;
- Seismic load OBE and SEE, with corresponding hydrodynamic load.

The loads combinations studied for static and dynamic analyses are summarized in Table 5-2.

Case	Ungrouted Dead Weight	Empty	FSL 540	MOL 467	OBE	SEE
Static - Empty	X	X				
Static - FSL540	X		X			
Static - MOL467	X			X		
Dynamic - FSL540 - OBE	X		X		X	
Dynamic - FSL540 - SEE	X		X			X

Table 5-2: Loads combinations

5.1.6. Results of Dam calculations

5.1.6.1. General

The results of the dam calculation are presented hereafter in term deformation and stresses for the static and dynamic calculations. The full details are provided in the Volume 5 Double curvature arch dam Ref. N° BG-DDR-Vol5-Rev0 and its Annex A1.

5.1.6.2. Static loading

The dam deformation under hydrostatic loading is illustrated in the following Figure 5-11 below

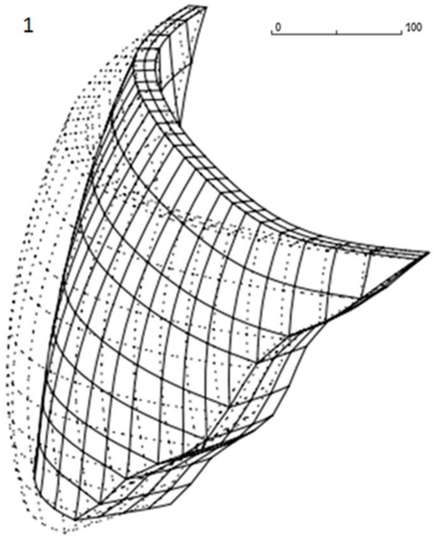


Figure 5-11: Dam deformation under hydrostatic loading

The maximum downstream deformation at cr est level is 17cm when the reservoir is reaching the FSL El.540. The maximum compressive stress is 12 MPa on the downstream face at the base of the dam.

5.1.6.3. Dynamic loading

The dam response to the dynamic solicitation simulated with 3 accelerograms calibrated for the OBE and for the SEE is illustrated in the following **Figure 5-12**.

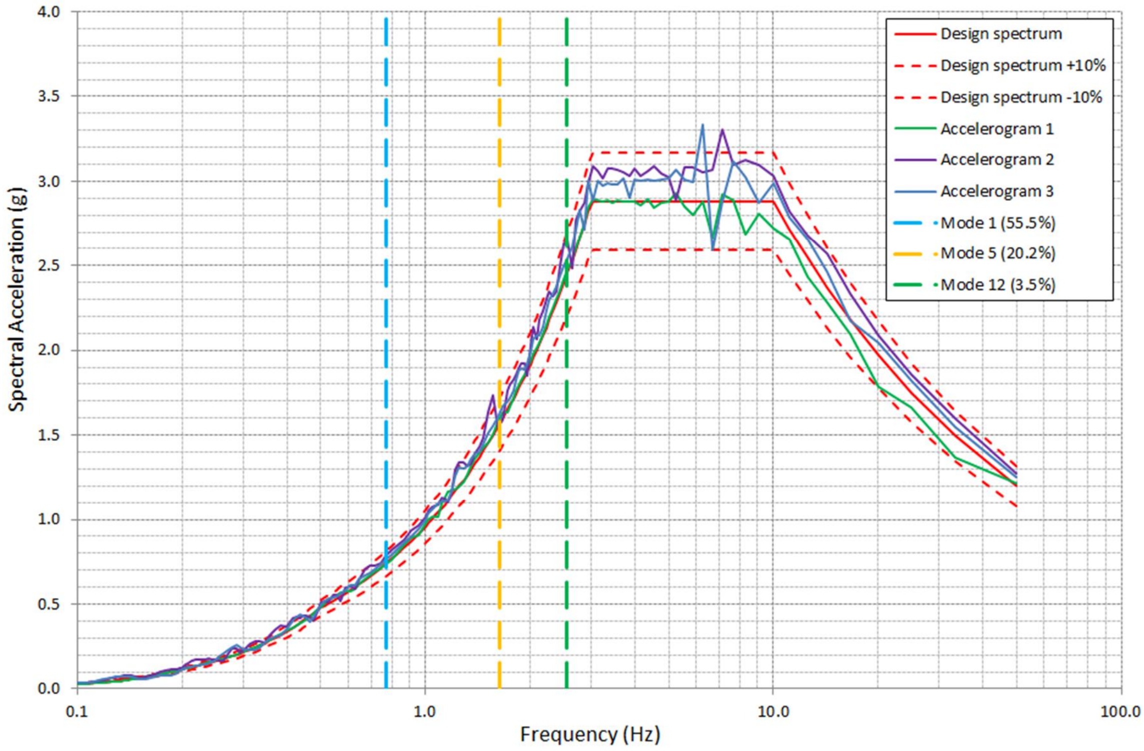


Figure 5-12: Associated accelerations to main modes

This figure highlights the fact that the dam vibration modes are out of the spectrum maximal acceleration range (from 3 to 10 Hz), proving that the dam design is well appropriated to the design spectrum. The following **Figure 5-13** illustrates the fundamental vibration modes in the upstream downstream direction.

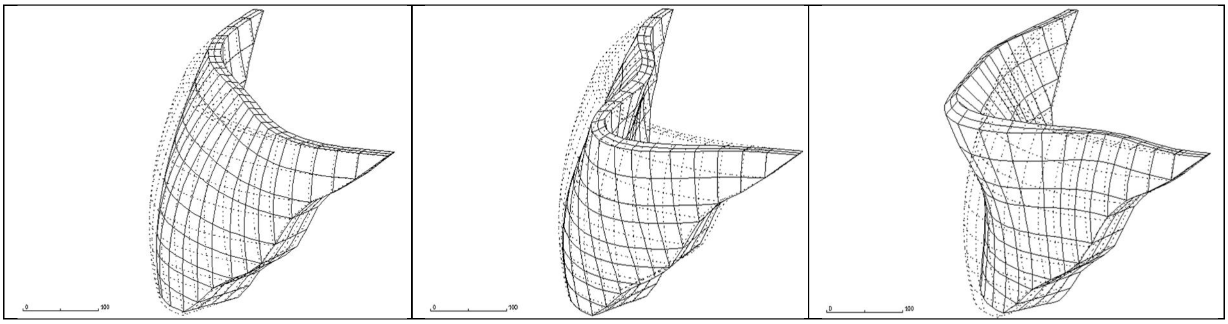


Figure 5-13: Vibration according to mode 1, 5 and 12
(Displacement x 3 500)

➢ **Displacements**

By analysing the maximum crest displacements during each accelerogram computations, the critical times for which the dam is subjected to a m aximum sollicitation have been identified.

The Table 5-3 below shows that the 3 accelerogramms are of comparable consequences, in terms of maximal displacements.

	OBE			SEE		
	Acc.1	Acc.2	Acc.3	Acc.1	Acc.2	Acc.3
Downstream (m)	0.40	0.33	0.34	0.62	0.51	**0.68**
T1 (s)	2.90	8.52	3.80	2.89	8.50	3.80
Upstream (m)	0.44	0.36	0.28	**0.61**	0.48	0.56
T2 (s)	3.40	8.91	3.31	3.40	8.92	3.31

Table 5-3: Maximum relative displacements at crest and associated times

The **maximum displacements** at the dam crest level for the SEE are **68cm downstream and 61cm upstream**.

- **Compressive and tensile stresses**

Dam behaviour during OBE

The dynamic behaviour during OBE shows that:

- Compressive stresses up to 26.7 MPa with a full reservoir supply level;
- Tensile stresses up to 13.8 MPa with a full reservoir supply level.

However, these peak values are very localized at the contact with the foundation, hilghlithing the transmission of efforts to the foundation.

To be noted that the high level of stress observed will occur during a ver y short time. Moreover, non-linear effects (tensions, joints openings) are not represented in this model, and must reduce the level of stress calculated.

Therefore, the dynamic dam behaviour in response to OBE is satisfactory.

Dam behaviour during SEE

Compared to OBE, the dynamic response to SEE increases in term of extreme values of stress (compression and tensile):

- Highest compressive stresses, up to 36 MPa with a full water supply level;
- Highest tensile stresses, up to 20.3 MPa with a full water supply level

For SEE, the levels of stress calculate give evidence of non-linear effects (tensile stress, joint opening), not represented in the linear model used. These stress levels will occur only during very short times. As conclusion, the behaviour of the dam against the exceptionnal case of SEE solliconclusioncitation is acceptable.

In conclusion, the static and dynamic computations of the dam allow to demonstrate the satisfactory behaviour of the dam with levels of displacement and stress compatible with the proposed construction technologies materials performances.

5.1.7. Abutment stability

As indicated in section 2.4 the natural combination of joints and weak zones prevailing in the rock mass of the dam foundation as well as the proposed excavations geometries (dam and powerhouse) could define potential rock wedges which behaviour under the dam thrust, the water pressure and the seismic loading would require appropriate stability verification.

The principle of rock wedges stability calculations is to calculate a force balance of the net weight of the rock mass wedge, as well as the resulting efforts from the dam, and water pressure.

In the reality, neither the right bank nor the left bank present combination of continuous joints (over 50 m or more) defining rock wedges which could be associated with a possible failure mechanism and kinematic.

Nevertheless and as a measure of additional safety a large rock wedge has been defined in the left bank for stability verification, assuming a fictive sub-vertical weak plane. Since this fictive weak plane is crossing the rock mass, a higher friction angle value has been adopted with respect to the other two planes (60°, instead of 48° for the two other planes) in the stability calculation.

The Figure 5-14 below represents this most unfavourable rock wedge that has been defined in the left bank and which stability has been checked.

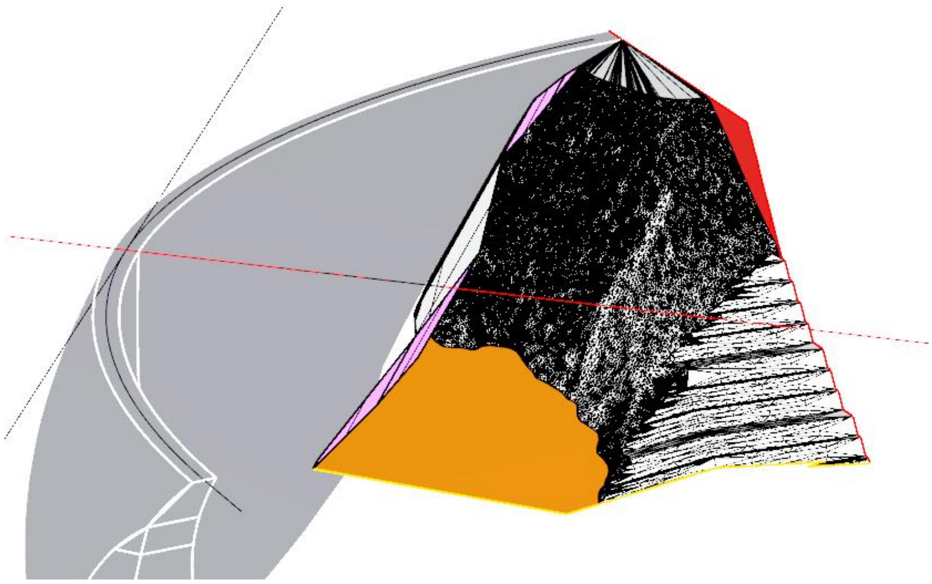


Figure 5-14: Left bank most unfavourable rock wedge

The static stability of this wedge is easily ensured with safety factor between 2.5 and 3.2 depending of hypothesis on the efficiency of the drainage.

For the verification under seismic loading the pseudo-static calculation has been associated with an in tegration of the displacements as per the Newmark's method using real accelerograms.

The analysis shows that, for the 12 combinations of accelerograms that have been tested, the maximum displacement doesn't exceed 4 to 6 millimeters.

It can therefore be concluded that given the geotechnical data currently available the rock wedge stability is not a critical issue on this project.

5.1.8. Dam excavations

The resistance and the modulus (rigidity) of the rock foundation are two critical aspects for the foundation of an arch dam (not only the resistance).

Extensive investigations by investigation galleries in the dam abutments and in situ tests suggest that the competent rock can be found at a reasonable depth between 20 and 30m.. Since explosive will be used for the excavation, consolidation grouting will have to be carried out systematically under confined conditions i.e. after placing the dam concrete.

Additionally, a curtain grouting, associated will drainage curtain, are necessary, to control the leakages and the pore pressures development in the rock mass under the dam and downstream.

5.2. Grout and Drainage curtains

Consolidation grouting is foreseen systematically along the whole surface of the dam footprint. Its main purpose is to repair the residual damage don't to the rock left in place by the excavation process. Consolidation grouting consists in short (10-15m) holes drilled from the surface or from the dam galleries and injected with cement grout. The typical pattern is 3 x 3 m.

Both grouting and drainage curtains cope with water leakage control in the foundation and especially water pressure control. The grout curtain is developed all around the dam footprint. The depth to be treated with the grout curtain has been based on the results of the core drilling and water pressure testing campaign. The grout curtain will therefore extend 120 m below the base of the dam. The curtain depth is progressively reduced up to the upper reach of the dam foundation (near the dam crest). It will consist in series of adjacent boreholes drilled from the different galleries implemented in the dam body and through the foundation. The drainage curtain is composed of adjacent holes drilled downstream of the grout curtain. The depth of the drainage curtain is adjusted to approximately 50% of the grout curtain depth.

5.3. Monitoring of the Dam

The displacements of the dam body will be monitored, with pendulums for horizontal movements (easy and accurate measures), and with leveling surveys in the galleries and monuments surveys outside for vertical and horizontal movements. Joint meters will also be placed across each contraction joint on the walls of the galleries. Several extensometers will also be installed in the foundation in order to measure the longitudinal displacements.
Independently from these displacement measures, monitoring of water in the foundation is very important, since these pressures can be critical for the stability of the dam. Therefore, piezometric cells will be placed at depth in the foundation, between the grout and drainage curtains. Also, the discharges in the drainage system will be measured, to detect abnormal variations of these flows (increase or decrease) requiring particular attention.
Also, for plant operation purpose, the reservoir level will be measured automatically.

The instrumentation foreseen in the dam is described in detail in Volume 5 section 5 and in drawings Volume 17 ref. BG-3-1-INS-001 to 004.

5.4. Spillways

5.4.1. Design criteria

The design criteria and data related to the specific functions of the spillway are presented here below. The following paragraphs differentiate the criteria related to hydraulic constraints, the criteria related to gates operations and also to the structural design of the sluices.

5.4.2. Hydraulic criteria

The discharge capacity of the spillway must be adapted to the natural hydrologic conditions of the Budhi Gandaki River. Reference is m ade to the Volume 2A-Hydrological and Meteorological Analysis Ref N° BG-DDR-Vol2A-Rev0 of the Final Detailed Design Report for the estimation of the floods peak discharges and volumes.

The following Table 5-4 and Figure 5-15 represent the different floods estimated at the dam site for various return periods and combination of hydrological events.

Return period T (years)	T= 10	T = 20 years	T= 50	T= 100	T= 500	T= 1 000	T= 5 000	T= 10 000	PMF	PMF+ GLOF
t (hours)	Discharge (m^3/s)									
0	893	932	981	1 017	1 150	1 148	1 247	1 278	1 230	1 230
3	893	932	981	1 017	1 150	1 148	1 247	1 278	1 230	1 230
6	893	932	981	1 018	1 151	1 149	1 250	1 282	1 236	1 236
9	894	935	986	1 025	1 163	1 167	1 277	1 314	1 292	1 292
12	912	960	1 024	1 073	1 232	1 253	1 394	1 446	1 522	1 522
15	1 051	1 134	1 245	1 330	1 567	1 638	1 871	1 964	2 417	2 417
18	1 406	1 559	1 769	1 926	2 316	2 473	2 875	3 042	4 276	4 276
21	1 946	2 196	2 534	2 785	3 379	3 639	4 252	4 510	6 803	6 803
24	2 446	2 775	3 217	3 542	4 301	4 636	5 409	5 737	8 912	8 912
27	2 709	3 070	3 552	3 904	4 728	5 082	5 909	6 260	9 809	12 809
30	2 690	3 035	3 493	3 827	4 615	4 941	5 720	6 049	9 443	9 443
33	2 479	2 780	3 179	3 469	4 164	4 436	5 113	5 397	8 318	8 318
36	2 177	2 425	2 752	2 989	3 569	3 783	4 339	4 570	6 895	6 895
39	1 885	2 085	2 346	2 537	3 013	3 175	3 624	3 808	5 583	5 583
42	1 636	1 794	2 002	2 153	2 542	2 662	3 022	3 167	4 481	4 481
45	1 439	1 566	1 732	1 852	2 173	2 261	2 551	2 666	3 618	3 618
48	1 290	1 394	1 527	1 625	1 894	1 957	2 196	2 288	2 967	2 967
51	1 184	1 270	1 381	1 462	1 695	1 741	1 942	2 018	2 503	2 503
54	1 108	1 182	1 276	1 346	1 553	1 586	1 761	1 825	2 171	2 171
57	1 053	1 119	1 202	1 263	1 451	1 475	1 631	1 687	1 933	1 933
60	1 011	1 069	1 143	1 197	1 371	1 388	1 528	1 578	1 745	1 745
63	980	1 034	1 101	1 151	1 313	1 326	1 455	1 500	1 612	1 612
66	958	1 008	1 071	1 117	1 272	1 281	1 403	1 444	1 515	1 515
69	940	987	1 046	1 090	1 239	1 245	1 361	1 399	1 438	1 438
72	929	974	1 030	1 072	1 217	1 221	1 333	1 369	1 387	1 387
75	919	963	1 017	1 057	1 199	1 201	1 309	1 345	1 344	1 344
78	912	955	1 007	1 047	1 186	1 187	1 293	1 327	1 314	1 314
81	907	948	1 000	1 038	1 175	1 175	1 279	1 312	1 289	1 289
84	902	942	993	1 030	1 166	1 165	1 267	1 299	1 266	1 266
Peak discharge (Qp) (m3/s)	2 730	3 090	3 570	3 920	4 740	5 090	5 910	6 260	9 809	12 809
Mean daily discharge (Q24) (m3/s)	2 246	2 520	2 884	3 151	3 789	4 044	4 673	4 937	7 530	7 905
Qp/Q24h (-)	1.22	1.23	1.24	1.24	1.25	1.26	1.26	1.27	1.30	1.62
Flood Volume - 3 days (MCM)	371	406	452	485	573	599	681	714	978	1 009
Kfr (Qp) - Catchment below 3 000m	4.67	4.78	4.91	5.00	5.17	5.23	5.37	5.42	5.82	6.07
Kfr (Qp) -Total Catchment	4.04	4.16	4.31	4.40	4.60	4.67	4.82	4.88	5.33	5.60

Table 5-4: Design floods – Detailed discharges and characteristics

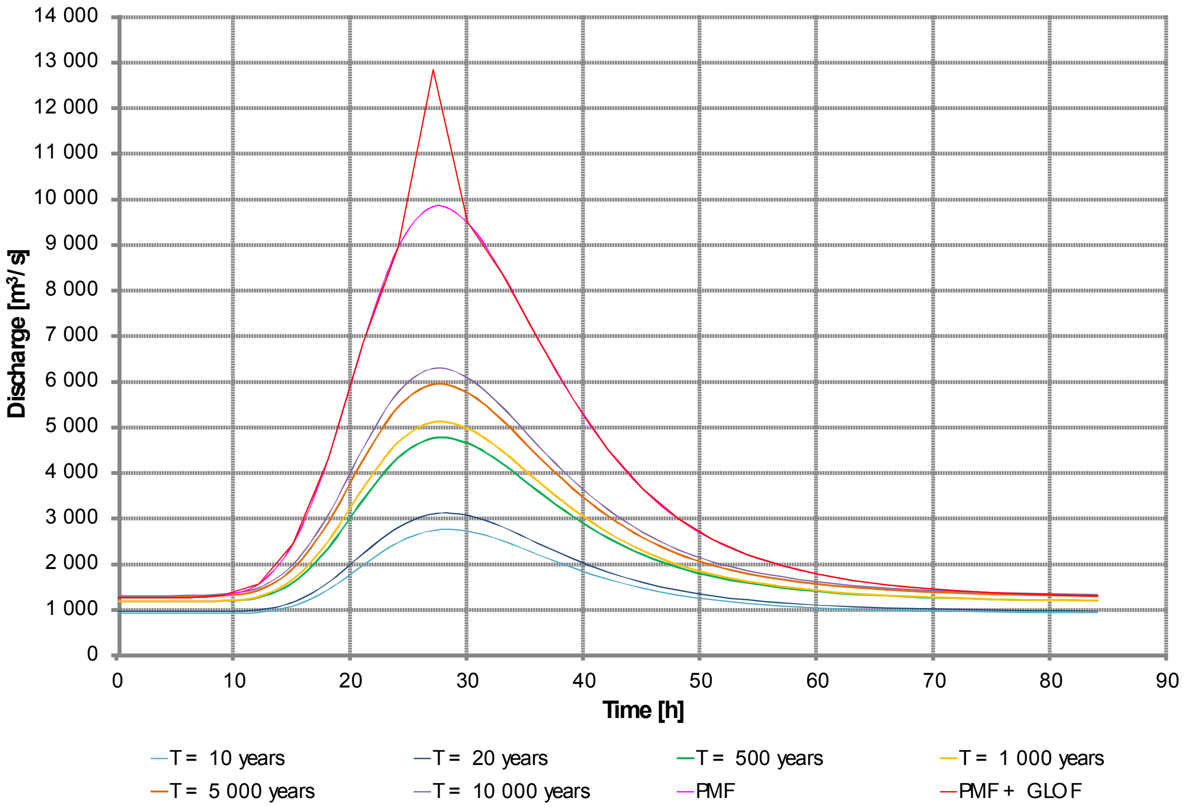


Figure 5-15: Design floods

It is to be noted that the flood management is carried out using the system of the spillway combined with the reservoir. Indeed, the routing effect of the reservoir in the flood management is to store temporarily a part of the flood volumes, thus decreasing the peak discharge of the floods evacuated by the spillway with respect to the peak discharge entering into the reservoir.

Particular design criteria for the spillway operation are imposed for reservoir routing calculations. Assuming N orifices spillway, the hydraulic design criteria are the followings:

For the 10 000 year flood, with N-2 orifices spillway, the maximum water level should be not higher than reference level 543 masl [(4)].

For the PMF, with N-1 orifices spillways, the maximum water level should be not higher than reference level 543 masl.

For the PMF+GLOF, with N orifice spillways, the maximum water level should be not higher than reference level 543 masl.

These criteria take into consideration the conditions of emergency and the possibility of maintenance or failure of the hydro-mechanical components of the spillway. It ensures the redundancy of the spillway structures to anticipate the potential gates operational constraints during dam exploitation.

Note [(4)]: The dam crest is at EL.542.00 and the upstream parapet at El.543.10

5.4.3. Spillway layout

After testing several configurations, within the framework defined by the design criteria, the Consultant converged toward an optimal configuration. This configuration has been tested on a physical hydraulic model at H ydro Lab Kathmandu (see section 16 of present document and also the complete report in Final Field Investigation Report Part B Appendix B5 – Ref. N° BG-INV-FNL-B5-Rev0), confirming the suitability of the defined layout, and allowing some minor adjustments on the design details of the scheme. The following paragraph gives a full description of the final spillway layout.

5.4.3.1. Optimal configuration

The optimal spillway configuration satisfying the outlined criteria is presented here below:

The number of bays is N = 6.

- This number allows ensuring the redundancy criterion;

The sill elevations are respectively 460 masl, 470 masl, 495 masl and 515 masl.

- The sluices are located at various levels, in order ensure a minimum flow velocity enhancing spreading of the evacuated flows within the impact area, and, in this way, optimize the ultimate plunge pool depth, extent and location;

The dimensions of each sluice at the outlet are standard: 5.6 m wide and 8.4 m high.

- With standard sized downstream gates dimensions, the design, handling, maintenance and operation of the gates are considerably simplified.

The following Figure 5-16 is a downstream elevation of the dam, presenting the spillway outlets layout. The arrangement is such that the spillway bays are distributed and each concrete block is equipped with 1 sl uice, except for the block n°0 which shows 2 bays respectively at levels 515 masl and 460 masl.

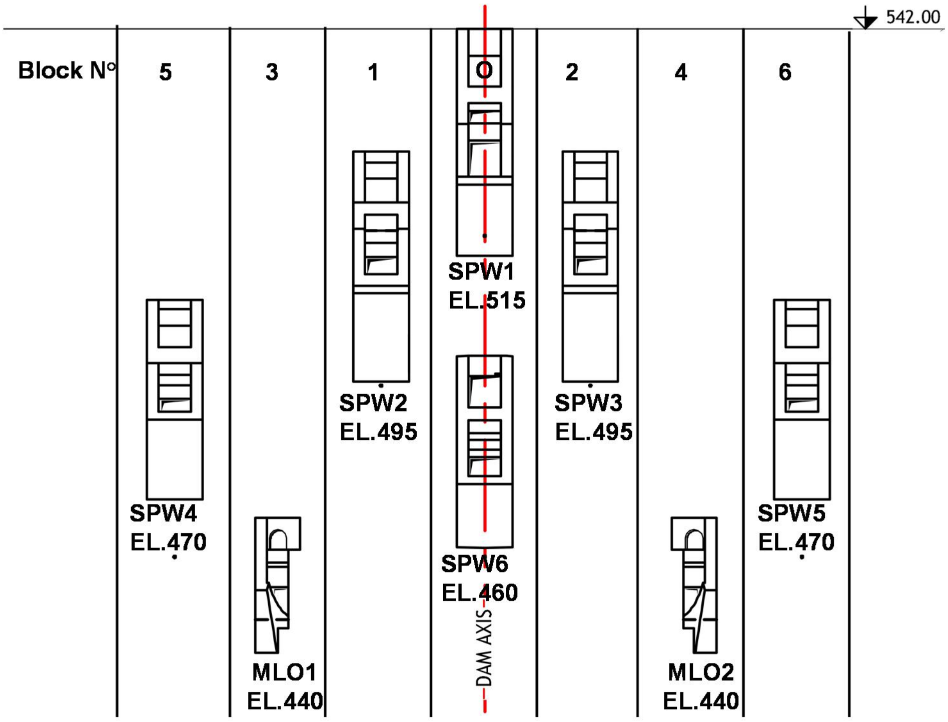


Figure 5-16 : Illustrative downstream elevation view of the dam - Spillway and mid-level outlets arrangement.

According to this layout, the blocks 0 (central block), 1, 2, 5 a nd 6 are equipped with spillway sluices, blocks 3 and 4 being dedicated to the mid-level outlets. The insertion of the mid-level outlets in blocks 3 and 4 improves the distribution of the spillway impacts, and also allow keeping the impacts of the mid-level outlets within the river boundaries.

Such a sym metrical distribution provides several advantages; including a good control of evacuated flows and impact conditions downstream the dam, the symmetry of scour erosions and a better spreading of the evacuated flows at the impact zone.

The following figure Figure 5-17 is a c rest plan view of the dam, showing the implementation of the spillway and mid-level outlets within U/S and D/S dam faces.

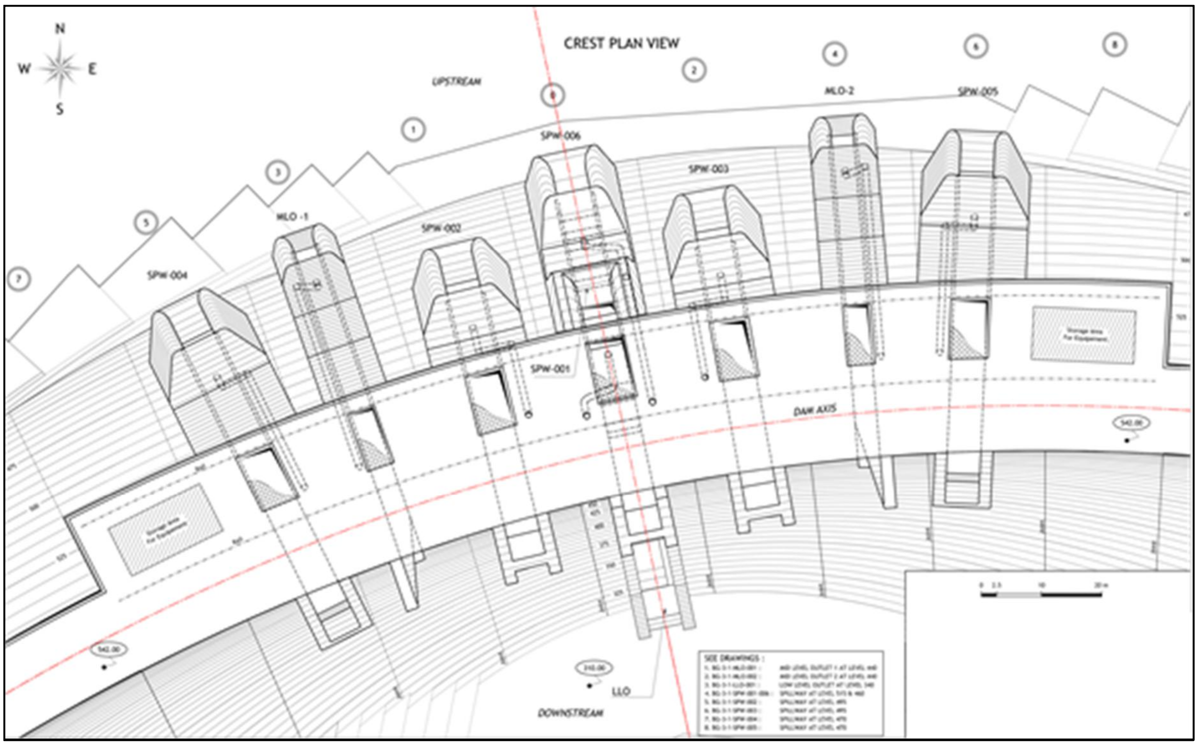


Figure 5-17: Optimal Spillway configuration – General plan view

The spillway layout has been defined in such a way that the impact zones of each sluice are well separated from the others, and that the total spillway jets energy is distributed optimally in the downstream plunge pool. The tailwater dam is also provided to ensure a sufficient water depth of the plunge pool, in view of reducing the scour and eliminate the need of costly bank stabilization measures.

Elevation [masl]	Number of bays [-]	Dimension [m^2]	Discharge capacity at FSL = 540 masl
515	1	5.6 x 8.4	792
495	2	5.6 x 8.4	1 115
470	2	5.6 x 8.4	1 421
460	1	5.6 x 8.4	1 526
TOTAL	**6**	**282 m^2**	**~7 400**

Table 5-5: Summary of spillway arrangement – Main dimensions

The following Figure 5-18 and Figure 5-19, represent the discharge capacity curves against reservoir level for each spillway bay, and also for the full spillway.

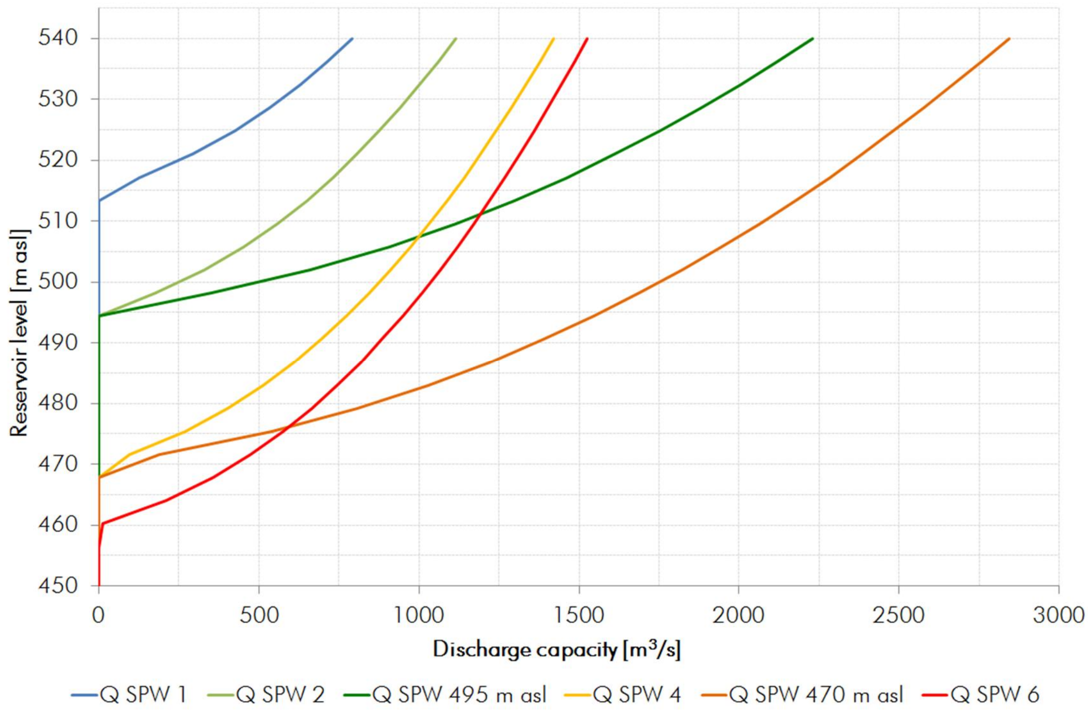


Figure 5-18: Spillway discharge capacity for each sluice

By summing the capacities of each outlet we obtain the total capacity curve of the spillway:

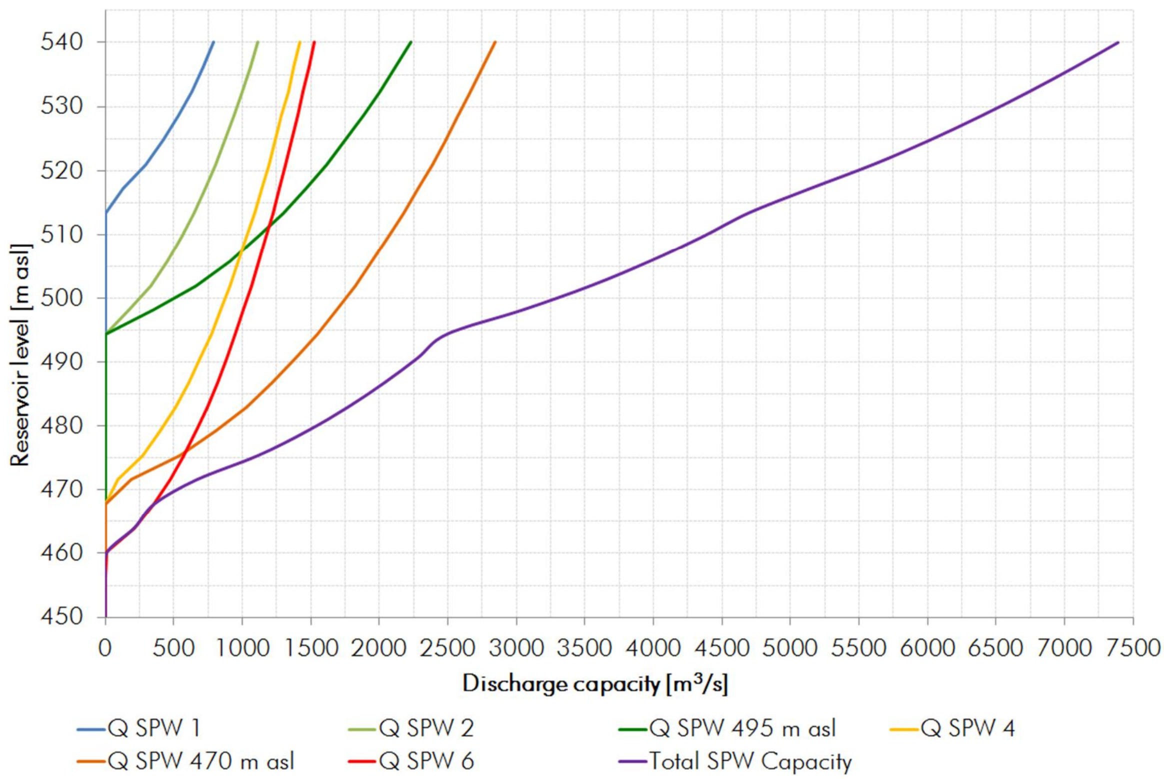


Figure 5-19: Spillway total discharge capacity

5.4.3.2. Sluice design

The sluices require two gates: the control gate and the maintenance gate.

Control gate is located at the downstream end of the sluice so that the required space for access, installation and maintenance is sufficient without compromising the dam structure. Radial gates are preferred for this function because they i) require no gate slots which are problematic for cavitation, and ii) allow partial openings operation for discharge control.

Maintenance gate is located upstream of the sluices, behind the inlet bell mouth transition. The maintenance gate must be able to close against the full flow. Fixed wheel gates have been chosen in order to allow the removal of these gates above the reservoir level for maintenance and inspection. This represents a significant advantage for maintenance, since these gates are of primary importance in case of emergency.

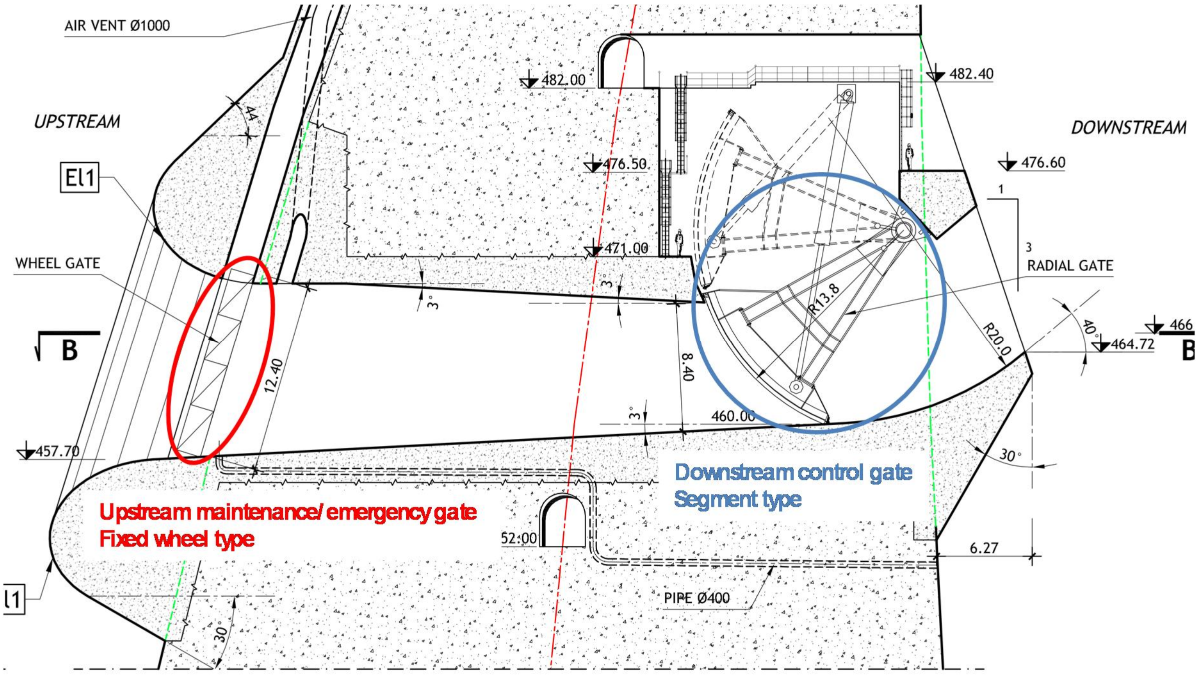


Figure 5-20: Spillway sluice - Position of gates

The sluice ahead of the control gate narrows down, conforming to a smooth elliptical shape for the upper part of the sluice, and the sluice slab is inclined towards upstream with a 5° slope. This convergent shape is imposed to ensure the convergence of streamlines which creates positive pressure along the structure boundaries, and counteract the high flow velocity likely to induce pressure drop, and potential cavitation.

Inlets are profiled following elliptical shapes, such that convergence is smooth. The elliptical shapes are determined according to reference document USACE – Hydraulic Design Criteria.

The following Figure 5-21 illustrates the design of the sluices as described previously:

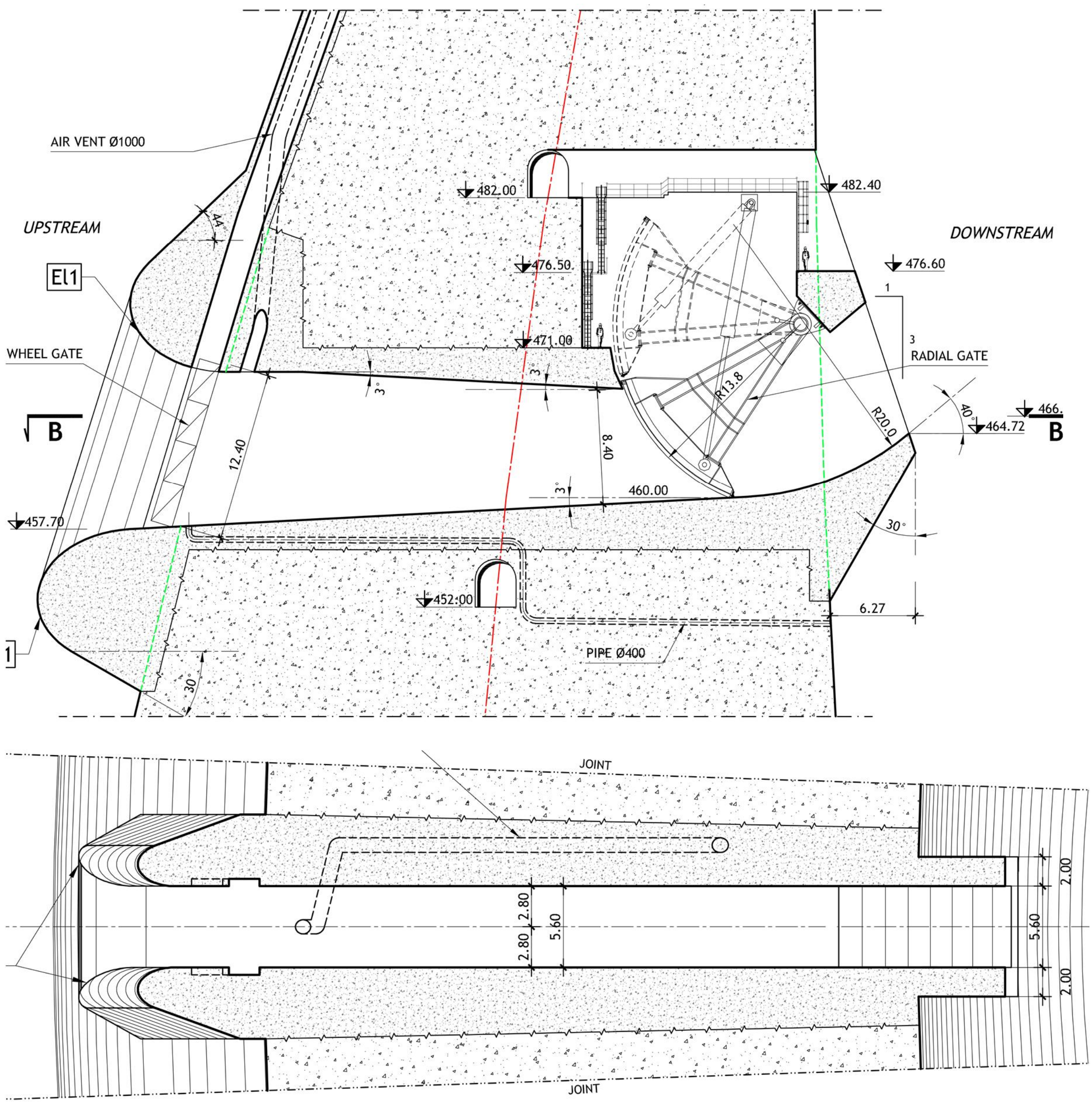


Figure 5-21: Spillway sluice – Typical section and plan view

5.5. Mid-Level and Low-Level Outlets

5.5.1. Mid-Level outlet – Design criteria

5.5.1.1. Hydraulic criteria

In case of failure or emergency situation, the rapid drawdown of the reservoir can be necessary in order to maintain the integrity of the structures and control the risks, by reducing the hydrostatic forces applied to the dam.

Typical standards for the design of bottom outlets require, among other safety measures, to lower the reservoir to 70% of its height (resulting in reducing by 50% the hydrostatic pressure on the dam). A period of one month to achieve this operation is considered reasonable with respect to the reservoir volume to be evacuated.

5.5.1.2. Structural criteria

The first criterion concerns the maximum head on the outlet. The structural criteria of low-level and mid-level outlets are the same as the one used for spillway sluices.

5.5.2. Mid-level Outlet Layout

By considering these criteria, the discharge capacity of the mid-level outlets is evaluated. These organs present a hydraulic behavior similar to that of an orifice.

The configuration selected is presented in the Figure 5-22 below. Two mid-level outlets are foreseen at the EL.440 masl. The level of EL.440 m asl is chosen such that the maximum hydraulic load on gates do not exceeds 100 m in normal operation conditions, in order, on the one hand, to keep reasonable operating conditions (flow velocity and stresses on hydro mechanical equipment due to water head), and on the other hand ensuring the sufficient water head to satisfy the discharge capacity criterion.

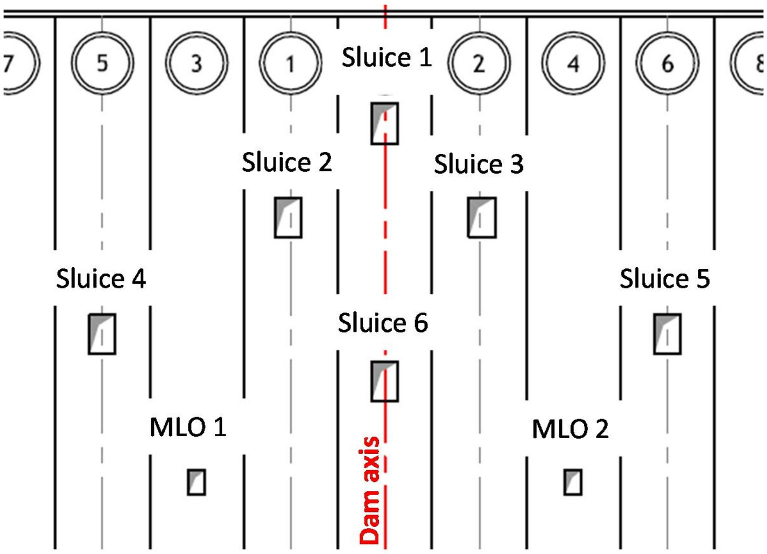


Figure 5-22: Downstream view – Mid-level outlets (MLO) and Spillway sluices

Once the hydraulic head and number of mid-level outlets have been fixed, the dimensions of the bays has been adjusted so that the discharge capacity is sufficient to satisfy the design criteria of a rapid reservoir drawdown, leading to dimensions of 3.7m x 5.55 m (width x height).

5.5.2.1. Sluice design

The structural criteria of mid-level outlets are the same as the one used for spillway sluice. The Figure 5-23 and Figure 5-24 below Figure 5-23presents the t ypical bay design proposed for mid-level outlets 1 and 2.

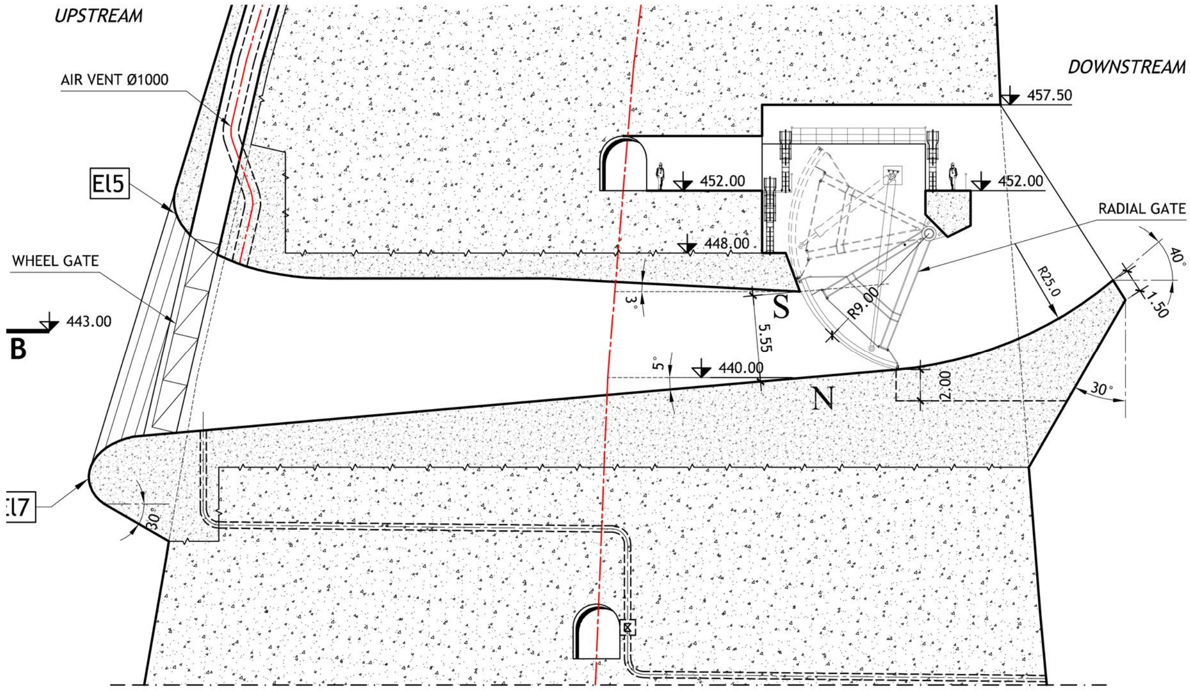


Figure 5-23: Mid-level outlet - Cross section A-A

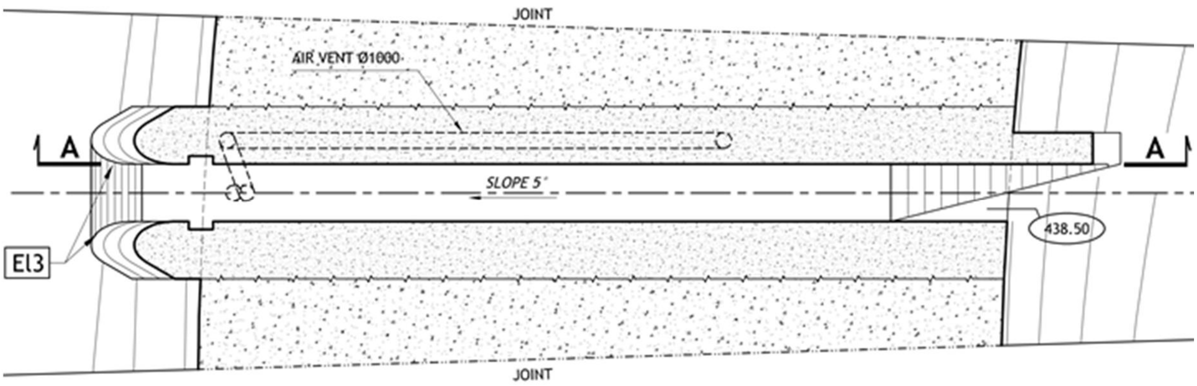


Figure 5-24: Mid-level outlet - Cross section B-B

5.5.3. Low Level Outlet

The reservoir rise shall be controlled as soon as the river diversions tunnels are closed. Therefore, it is advisable to have a low-level outlet in the low elevations of the dam, in order to immediately manage the filling of the reservoir.

Low Level 0utlet shows the same dimensions as spillway outlets (8.4m x 5.6m), firstly to ensure a sufficient discharge capacity, but also to allow the possibility of re-using some of the hydro-mechanical equipment from this temporary structure, to definitive spillway outlets.

The Low Level Outlet will be permanently closed and sealed during the reservoir first filling operation and before the head exceeds 100m.

The following configuration of outlets is fixed in order to respects the design criteria:

Rectangular outlets (width x height)	8.4m x 5.6m
Number of outlets:	1
Elevations:	340 masl (Low-level outlet 1)
Discharge capacity:	840 m^3/s under 25m head

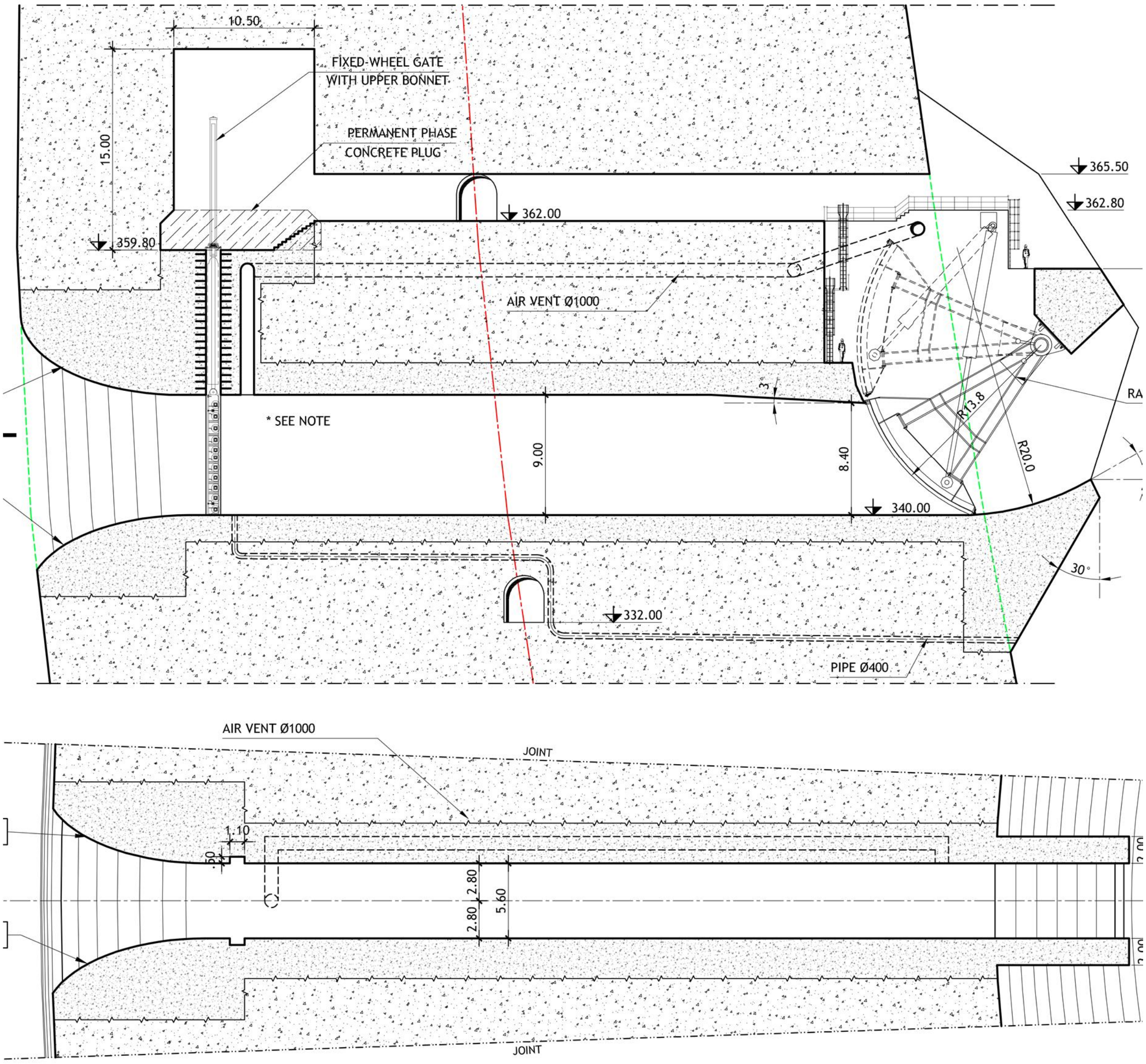


Figure 5-25: Low Level Outlet - Sluice design – Section and plan view

5.6. Tailwater dam

In order to reduce the erosion potential and the depth of the scour hole generated at the impact zone of the spillway jets and to avoid the need of costly bank stabilization measures, it is necessary to increase the water depth of the plunge pool in view of achieving a better energy dissipation. For that purpose a tailwater dam has been designed. This tailwater dam is positioned immediately upstream of the tailrace channel of the powerhouse, in order to avoid impacting the head on the powerhouse units and the power generation performances.

The tailwater dam is depicted in the Volume 17 Drawings Ref. BG-3-1-SPW-201and 202.

The Figure 5-26 below illustrates the general layout and sections of the tailwater dam.

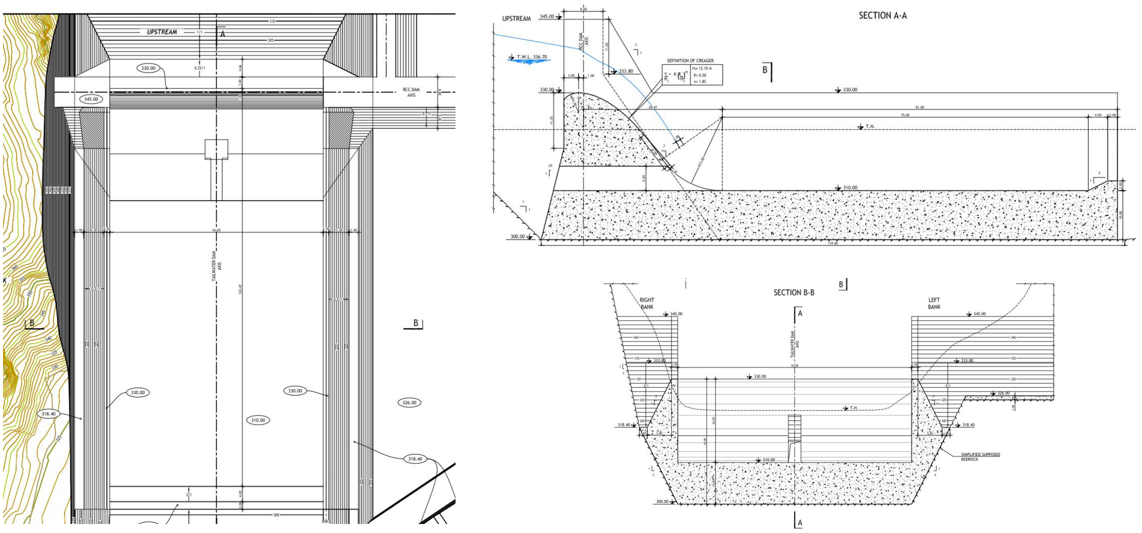


Figure 5-26: Tailwater dam

5.7. Diversion Works

The diversion of the Budhi Gandaki river during the 4 years construction of the dam before reservoir impounding will be made through two concrete lined diversion tunnels of about 400 and 430m in length each with a 12m internal diameter excavated at the river level in the left bank. These tunnels combined with a 37m high upstream cofferdam (El.357masl) and a 13m high downstream cofferdam (El.332.50masl) will allow safely diverting a flood of about 3200 m^3/sec which is slightly higher than the selected 20 years return period construction flood estimated to 3070 m3/sec.

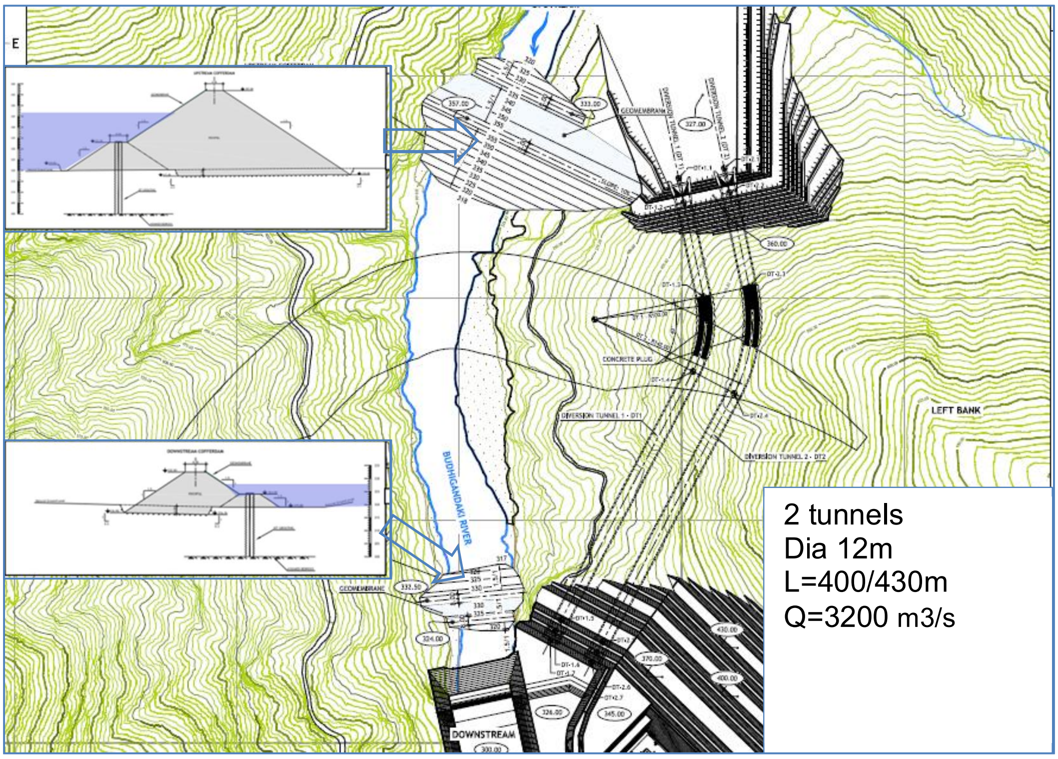


Figure 5-27: Diversion works general layout

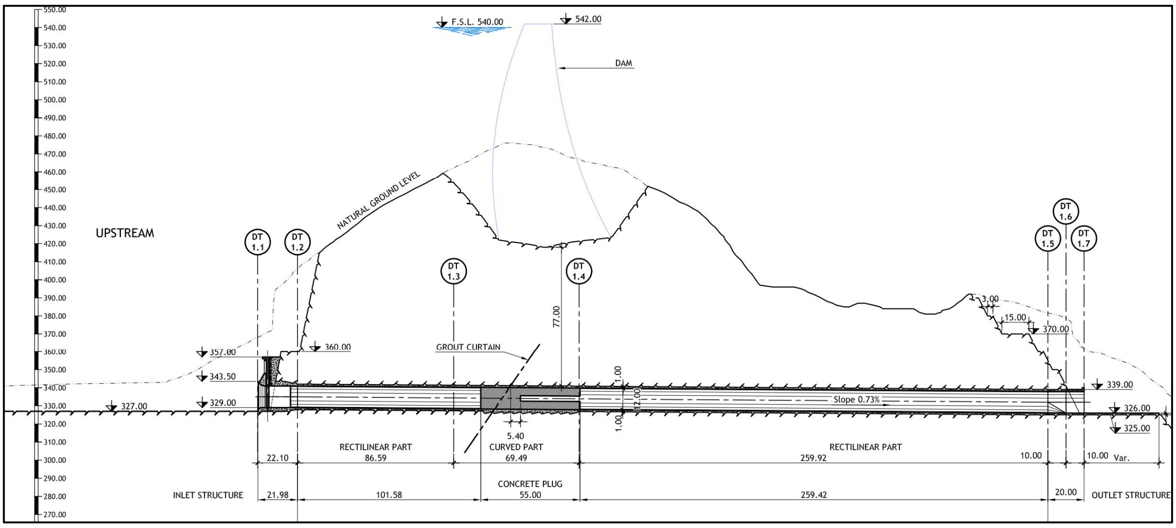


Figure 5-28: Diversion tunnels – Longitudinal Section (DT1)

6. DESCRIPTION OF THE WORKS – WATERWAYS

6.1. General Layout of the waterways

The system intake/waterways located in the left bank abutment conveys the water from the 5.7 Mm^3 water reservoir to the 1200MW capacity power house.

The six waterways are independent and have varying total length ranging from 695m long (Unit 6) to 787m long (Unit 1). They consist in:

a) **Six intakes**, bell mouth shape built at El.450 , with a 40° angle slope from the vertical and equipped with trashrack, operated by a crane from an upper platform at El. 542masl,

b) **Six intake tunnels**: 107m long and 6m inner diameter concrete lined, 0.50m concrete lining thickness,

c) **Six gate shafts** 100m high each equipped with a bulkhead gate and a service gate operated from a com mon control gate chamber at El 544,60masl. An upper El. 554,60masl platform is equipped with a gantry crane and the hydraulic hoists,

d) **Six upper headrace tunnels:** between 87 m long and 165m long, 5.3m diameter steel lined, and 22m steel lining thickness,

e) **Six pressure shafts** of around 140m high each, and steel lining thickness varying between 28mm and 45mm,

f) **Six penstocks** between 352m long and 365m long with 45mm steel lining thickness,

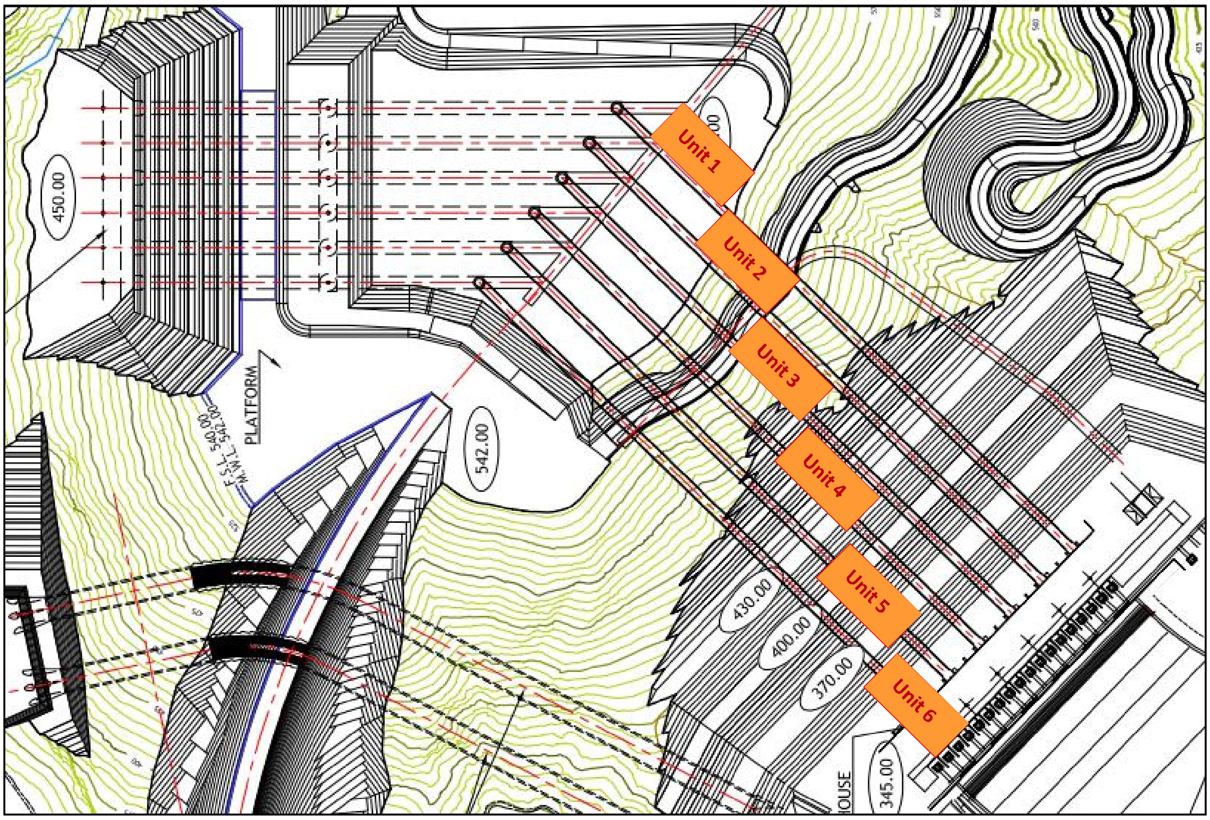


Figure 6-1: General Plan View of Intake & HRT

(Vol 17 – BG-3-1-DAM-002)

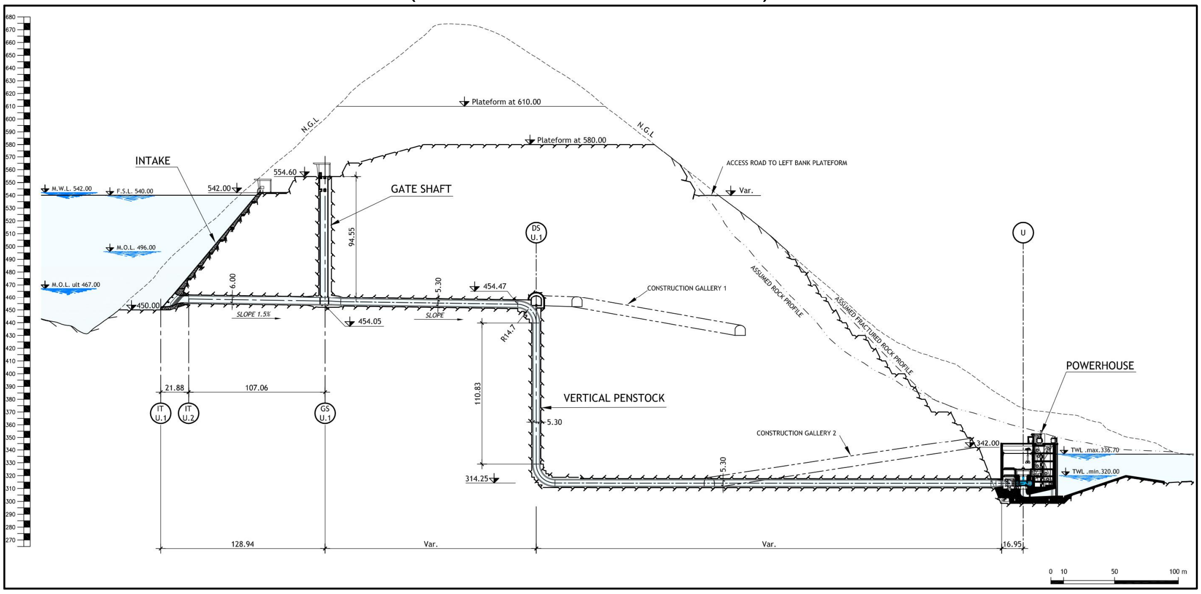


Figure 6-2: General Longitudinal Section of Unit n°1
(Vol.17-BG-3-2-GEN03)

The waterways structures are described from upstream to downstream in the following sections.

6.2. Power Intake structure

The six power intake structures are located on the left bank of the dam. The **intake structure works** consist in:

i. **An inclined fixed trashrack**, 40° from the vertical, with an inlet sill fixed at El. 452,50masl.

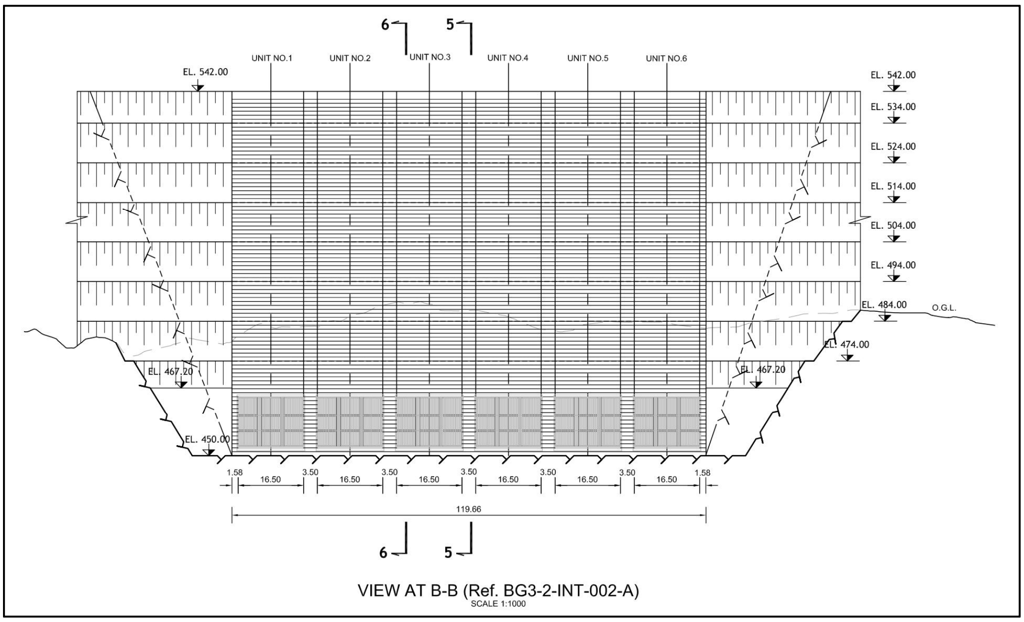


Figure 6-3: Front view of intake – Trashrack
(Vol.17 – BG-3-2-INT-006)

ii. **<u>A bell mouth inlet structure</u>**, with an elliptic shape hydraulically optimized. The bell mouth inlet structure is almost 22m long from the rectangular invert at El. 452,50m to the beginning of the circular 6 m diameter tunnel at El. 455,60masl.

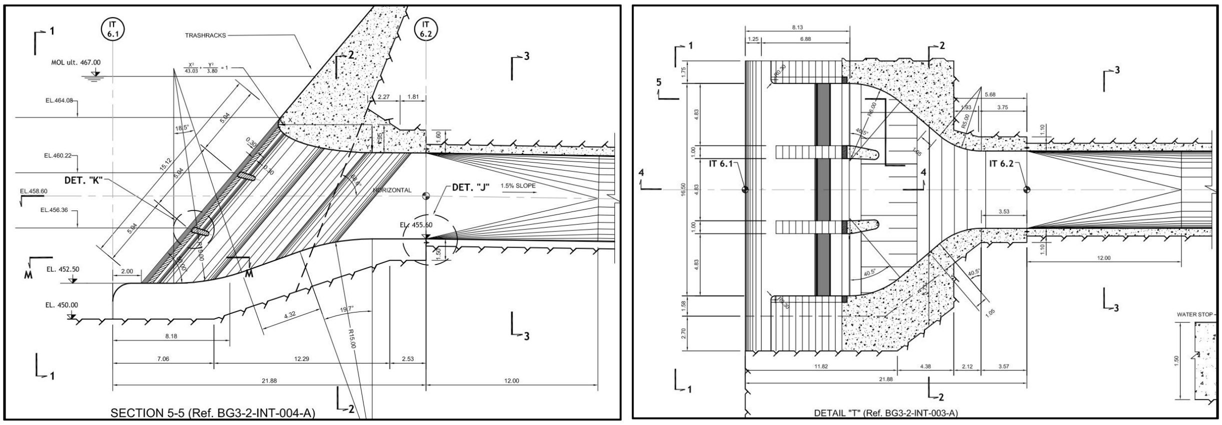


Figure 6-4: Intake Longitudinal and horizontal Section
(Vol.17 – BG-3-2-INT-004 and 005)

6.3. Intake Gates shafts and maintenance chamber

The intake gates will be operated from gate shafts drifted into the rock mass, and located slightly upstream of the dam grout curtain, roughly 110m downstream the intake structures.

The system is composed of:

i. **<u>The interconnection shaft to HRT</u>,** 26.7m long, including the transition from the circular concrete lined tunnel to the gate rectangular section, the bulkhead gate and service gate rectangular seal planes connecting to the shaft and the downstream second transition connecting to the 5,3 m diameter circular steel lined HRT,

ii. **<u>The gate shafts</u>**, 10m excavated diameter and 100m high are equipped with :
   - a bulkhead gate, invert level at El. 454masl, upstream sealing plane,
   - a service gate, invert level at El. 454masl, downstream sealing plane,
   - two air vent steel pipe (diameter 1m),

iii. **<u>The common control gate c hamber</u>** at El. 544,60m, 110m long , 10m hi gh and 8.8m wide foreseen for gate maintenance,

iv. **<u>An upper El. 554,6masl platform</u>** equipped with a g antry crane for the maintenance and the hydraulic hoists for the operation of the service gates.

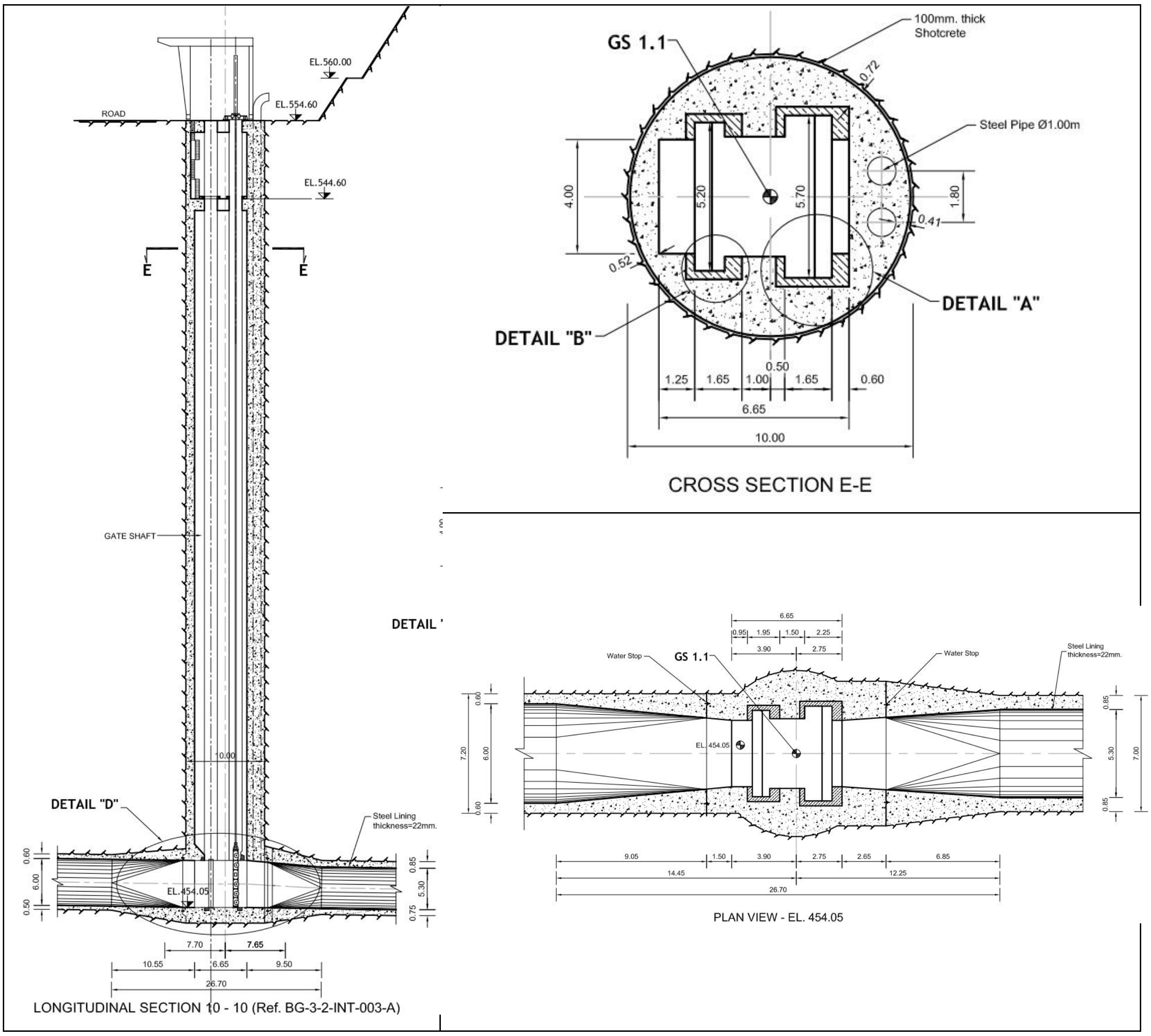


Figure 6-5: Gate Shaft – Gate section - Lower transitions
(Vol.17 – BG-3-2-INT-011)

6.4. Intake and headrace tunnels

The six independent tunnels are each composed of:

i. <u>A concrete lined intake tunnel:</u>

The intake tunnel, 0.5m thick concrete lined, 6m inner diameter and 107m long connects the bell mouth inlet to the gate shaft, with a slope of 1.5%.

ii. <u>A steel lined headrace tunnel:</u>

The length of the 5.3m inner diameter tunnel, with a 22mm thick steel lining, varies from one unit to the other, 165m (Unit n°1) to 87m (Unit n°6), and connects the gate shaft to the pressure shafts with a slope of 1.5%.

iii. <u>A steel lining pressure shaft:</u>

The pressure shafts are 140m high, 5,3m inner diameter and have a variable steel lining thicknesses from top to bottom in three uniform sections with 28mm , 35mm and 45mm.

iv. A steel lining penstocks:

The penstocks conduct the water to the powerhouse with an internal diameter of 5,3m and a steel lining 45mm thick.

6.5. Outdoor excavations

To ensure stability of the slope, the main front of the intake excavation will not exceed the angle of foliation. Slope stability measures adopted are the following:

- 10 cm thick steel mesh reinforced shotcrete and weepholes.
- 6 m long anchors, @ 6x5 (HxV).

6.6. Gate Shaft and Gate Chamber

Each of the 6 tunnels is equipped with a dedicated service gate or the Fixed-Wheel type. The main purpose of these gates is to protect the powerhouse equipment and personnel in emergency and maintenance conditions. Hydraulic hoists have been chosen, they are located in dry conditions at El.554,60 m. Between the tunnel and the surface, each gate will travel in a gate shaft fitted with slots and rails.

For maintenance purpose, 3 identical bulkhead gates have been foreseen, they can be use to close any of the tunnels. Similarly to the service gates, they travel in slots located in each of the 6 gate shafts. They are positioned by a common gantry crane located at elevation 554,60 m.

The storage of the bulkhead gates and lifting links of the service gates is foreseen in a gate chamber at El.544,60 m

6.7. Temporary Support

The quality of the rock mass has been determined and ordered in five classes associated to five typical sections of rock support. These five qualities of rock have been associated to an occurrence corresponding to the geological context in the left bank:

RMR		Occurrence	Rock Support
Class	Value	%	Typical section
II	61-80	5	1
III a	51-60	25	2
III b	41-50	35	3
IV	21-40	30	4
V	0-20	5	5

Table 6-1 : Occurrence of rock support sections in HRT

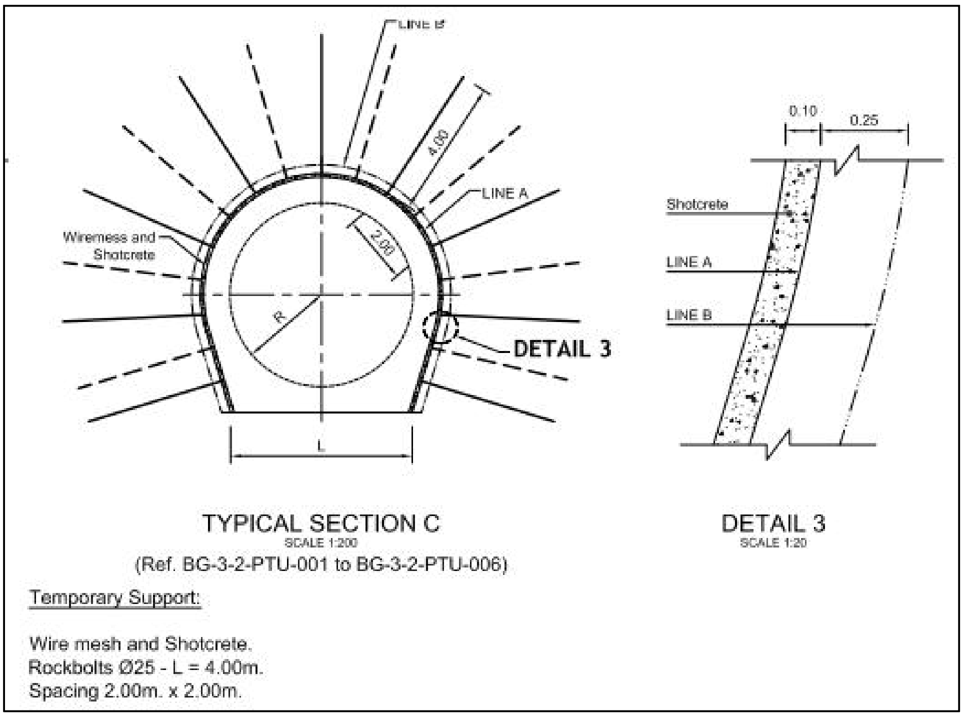


Figure 6-6: Rock Support -Typical Section (extract Ref PTU-012)

6.8. Steel Lining design

The steel lining design of the waterways is presented in the **Volume 7 – Intake and waterways**, the main results are summarized in the figure below.

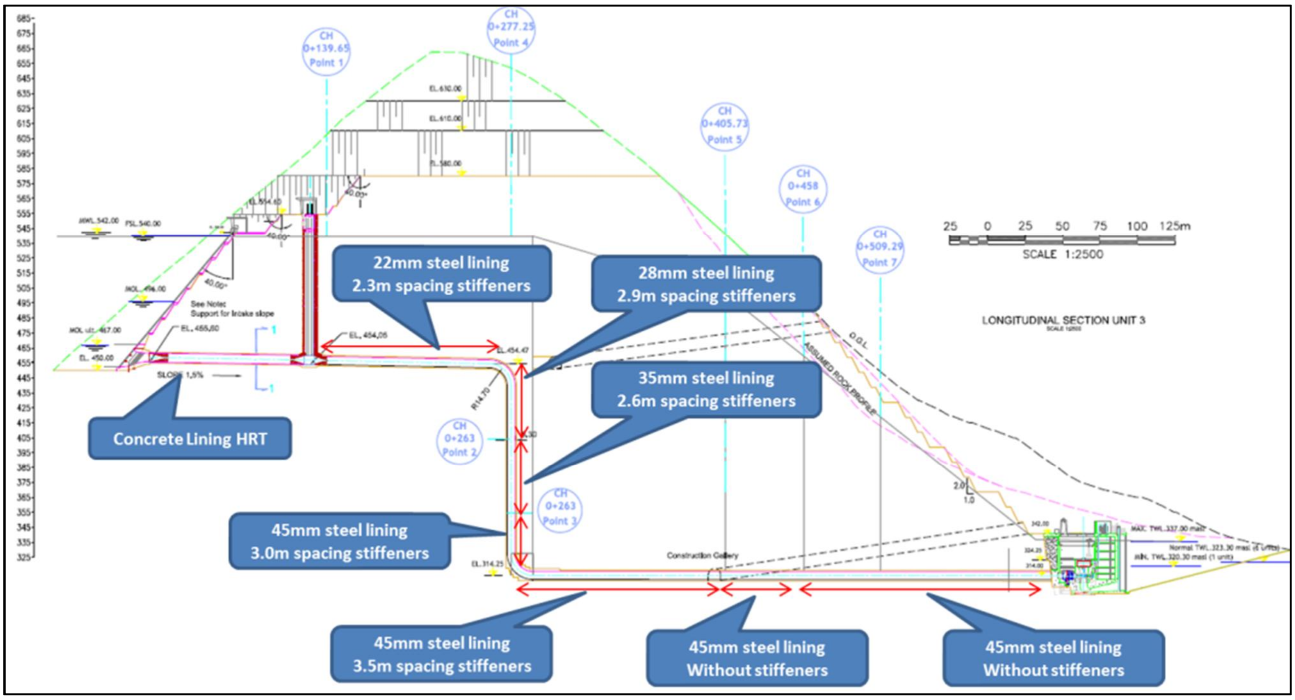


Figure 6-7: Summary of the steel liner and stiffeners dimension.

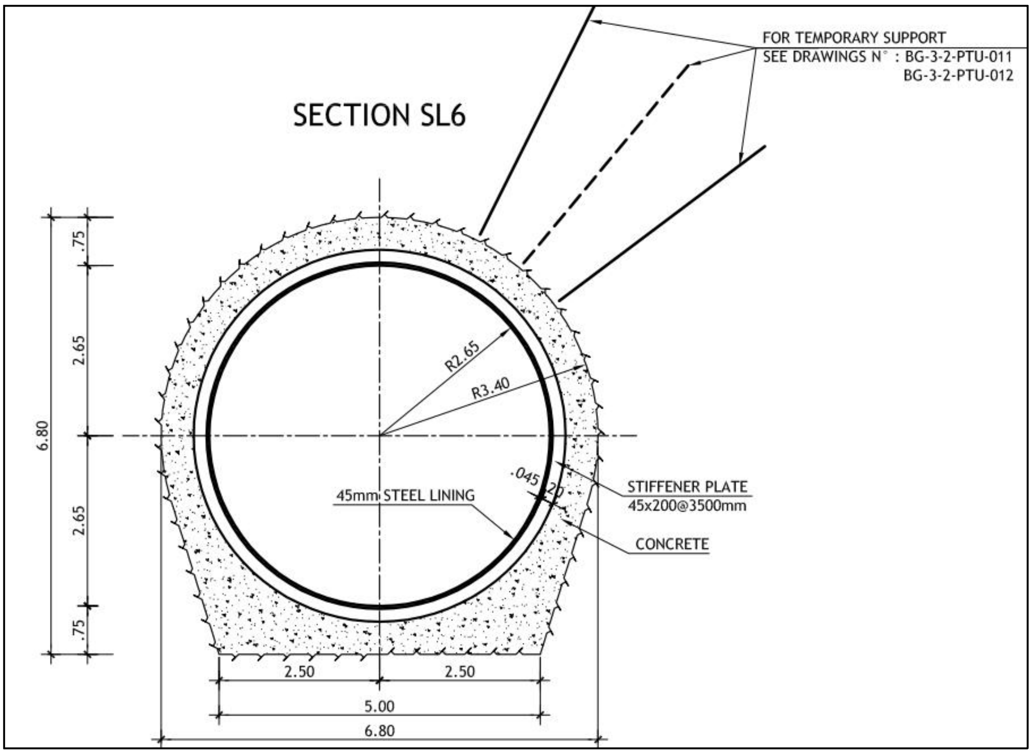


Figure 6-8: Headrace Steel lined tunnel -Typical Section

6.9. Access tunnels

Two access galleries and operation chambers are foreseen for the excavation and the steel lining erection in the HRT's and in the shafts:

- An upper access gallery and six operation chambers reaching the upper part of the pressure shafts (permanent access),
- A lower access gallery starting from the power house El. 345 platform and reaching the lower part of the HRT's (temporary access),

7. DESCRIPTION OF THE WORKS – POWERHOUSE

7.1. General Layout

The surface powerhouse is located on the left bank, approximately 500m downstream of the dam. The main access is provided by two bridges, one across the Trishuli River and the other one across the Budhi Gandaki River.

The powerhouse dimensions are: approx. 46.5m height, 44.4m width, 215 long and distance between two unit centre lines is 25.35m.

The main access being at EL. 345 masl, all the equipment will be lowered on the erection bay at EL.325.20 masl by the main hatch protected by a removable metallic roof.

The bottom of the excavation for power house is at 298.50masl, the elevation of the center line of the turbines is at EL.314 masl. Then several floors are foreseen for accommodation of the main and auxiliary equipment's, their operation, maintenance up to the surface platform. The surface access platform elevation is El.345 masl. It includes the access, the transformer bays, the gantry crane for operation and maintenance.

The Figure 7-1 here after illustrates the general layout of the Powerhouse complex

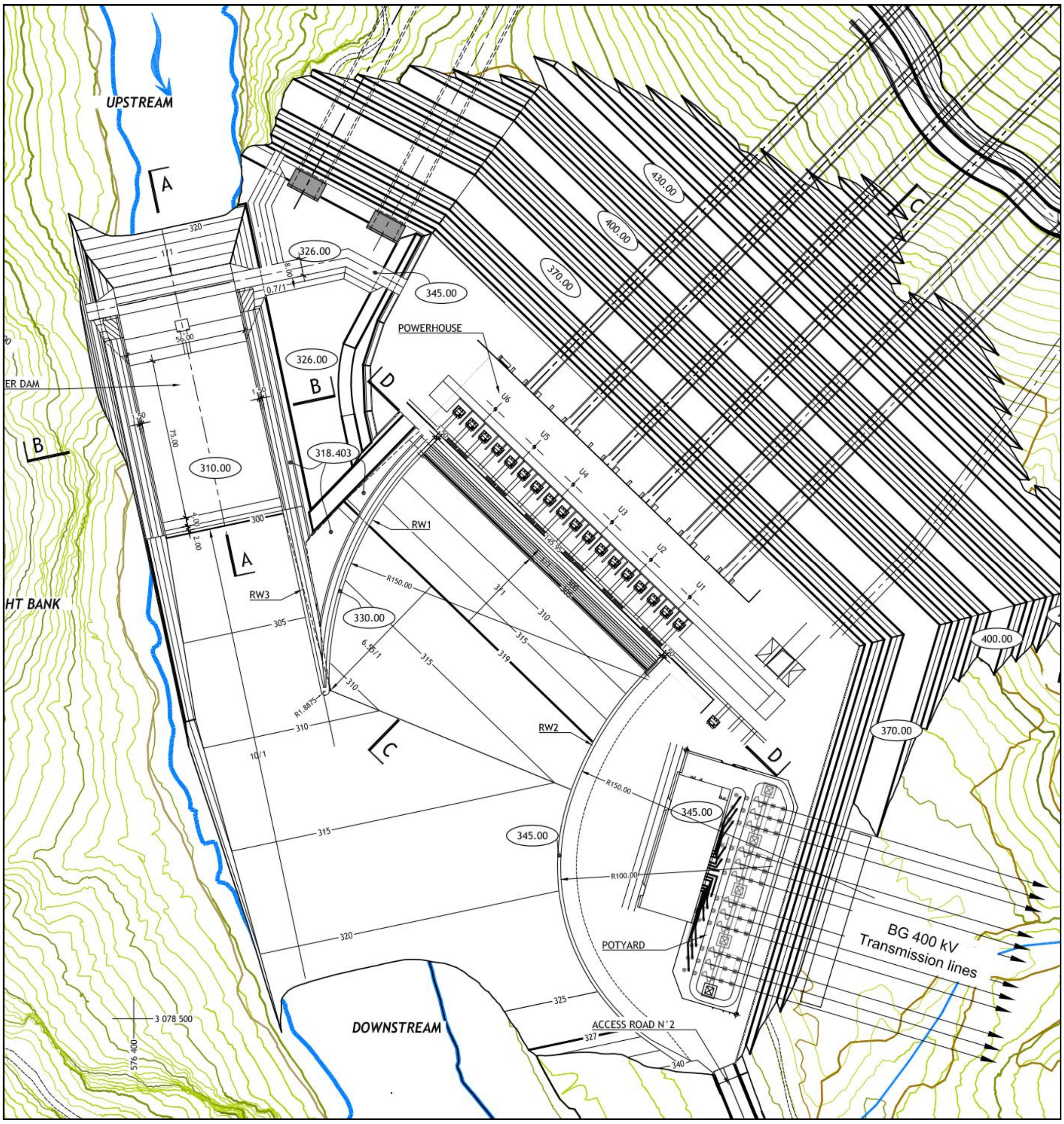


Figure 7-1: Powerhouse General Layout
(Vol.17 – BG-3-1-PWL001)

7.2. Civil works

7.2.1. Internal arrangement

Several floors are foreseen for accommodation of the main and auxiliary equipment's :

Levels	Elevation (masl)
Drainage gallery floor	300.00
Bottom of Tailrace Channel	304.00
MIV Floor	309.50
Mechanical Floor 1 (compressor room, cooling water and water treatment equipment)	311.00
Mechanical Floor 2	315.50
Generator Floor	319.70
Erection Bay Floor	325.20
Workshop	325.20
Control System Floor	331.40
Administrative Floor	337.60
E.O.T Crane Beam Level	338.00
Transformer Hall Floor Level, Diesel Generator Room and Fire Protection Room	345.00
Ventilation room	350.20

Table 7-1: Powerhouse levels

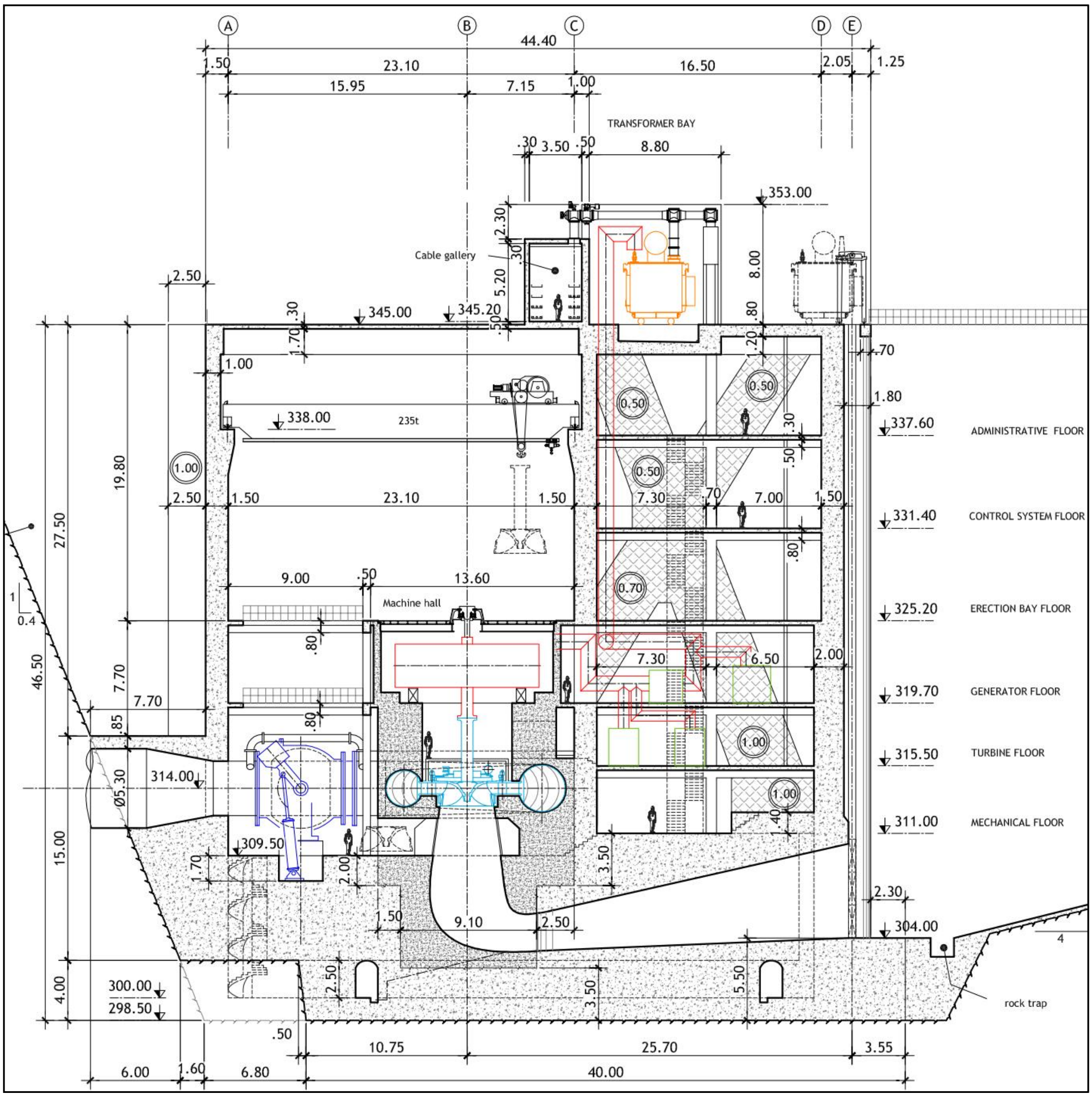


Figure 7-2: Powerhouse Section
(Vol.17 – BG-3-1-PWL-005)

7.2.2. Tailrace and outlets works

The tailrace channel is located at downstream end of the powerhouse. It is set as an extension of the powerhouse draft tubes. The tailrace channel main function is to allow the powerhouse outflows to join the Budhi Gandaki river with smooth and controlled hydraulic conditions.

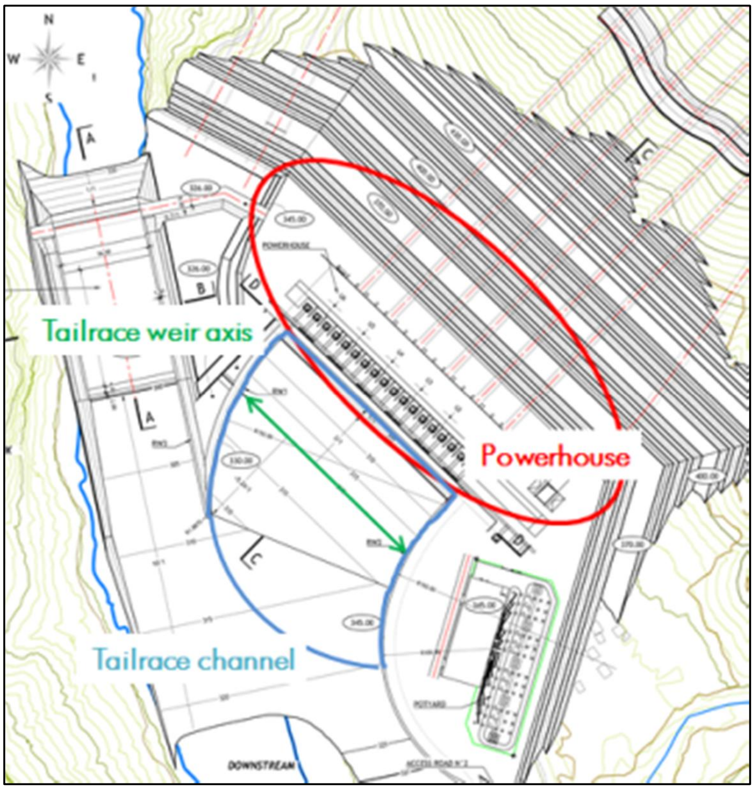


Figure 7-3: Tailrace channel - Plan view

Since the powerhouse orientation is nearly perpendicular to the River, the tailrace channel is designed so as to conduct the flow in a smooth curve joining the River. A weir is foreseen in order to control the water levels, and ensure a minimum head over the powerhouse turbines for appropriate operation in minimal condition, which is defined by the case of 1 unit starting operation.

The turbines operation conditions impose in this case that water level do not get below EL.320 m asl.

The tailrace channel is edged by two retaining walls. The right bank wall aims to limit and protect the potyard plateform located at El. 345masl. The left bank wall separate the tailrace channel from the downstream release area of the tailwater dam.

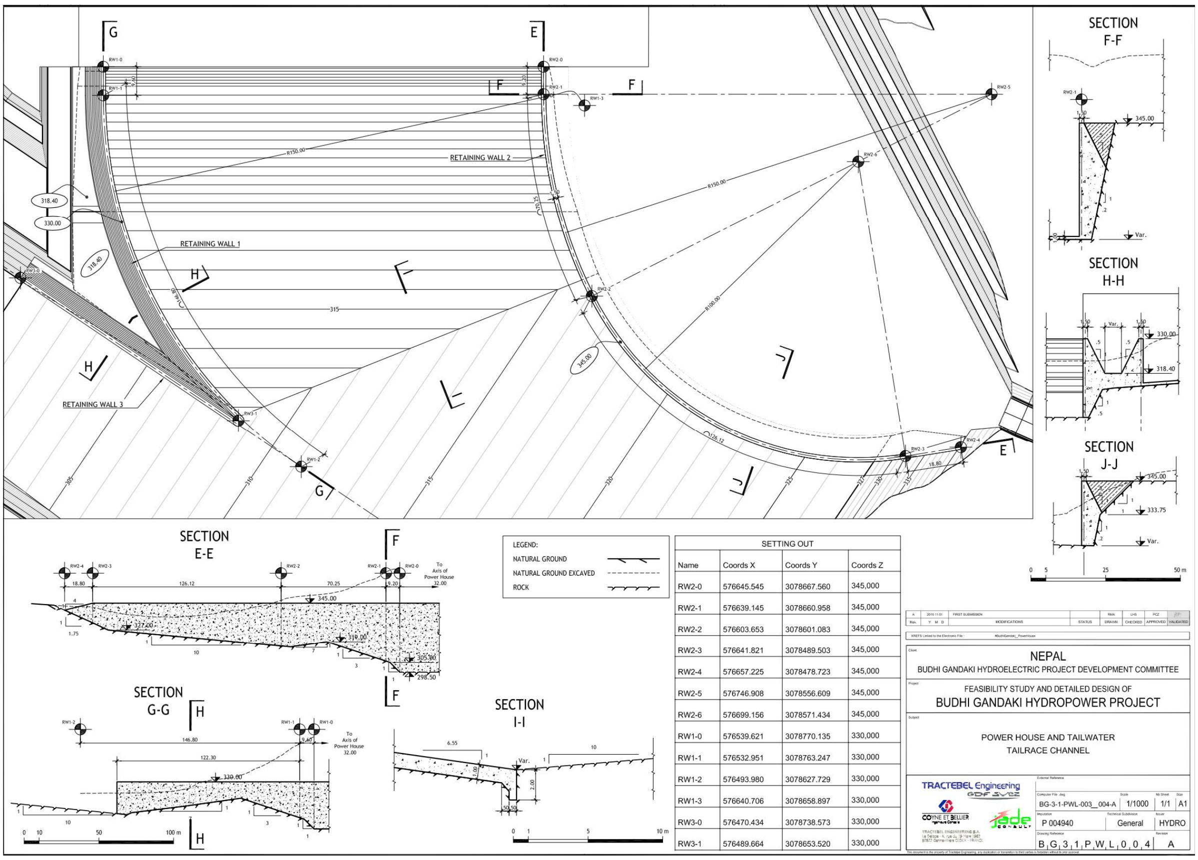


Figure 7-4: Tailrace channel – Plan view
(Vol.17 – BG-3-1-PWL-004)

The upstream face of the tailrace is a 1V:3H slope, and the slope located downstream to the weir is smoother, about 1V:7H.

It is foreseen to build a concrete slab for the upstream face of the tailrace, the downstream face is not covered, considering the flow velocities involved in the powerhouse release discharge are quite low, and does not represent a significant erosion potential on a rock foundation.

7.3. Hydro and Electromechanical equipment

7.3.1. General

The powerhouse shall house six generating units and all associated accessories to allow for its safe and reliable operation. The number of units is chosen as minimum as possible, while allowing energy generation over a wide flow range. Transportation limitations are considered and the size of the units is such as the power does not exceed 10% of the total Nepal Power System at the time of commissioning.

The turbines are 6 vertical shaft type Francis type, coupled to a Generator of a rating of 200 MW each reached under a rated head of 200 m.

The Generating Units are spaced at a distance of around 25 m. The length of the Erection Bay is proposed as 33.0 m. The Erection Bay (33.0 m long) shall be at EL 325.2 m. One main loading bay and a smaller one are foreseen from each side of the power house, to store equipment before reaching the erection bay.

The Length of Powerhouse (including Erection Bay and Auxiliary rooms) is 215.0 m. The width of the powerhouse is around 44.40 m.

19 nos., of 15.5kV/400 kV√3, 78.5 MVA transformers (including one spare) shall be located in the transformer hall. The overall length and width of the Transformer hall shall be 184.6 m and 16.50 m respectively.

Two Auxiliary Transformers 15.5 kV/0.400 kV, 4000 kVA shall be located in the electrical auxiliary floor. The 2 diesels 1000kVA, 400 V, shall be located in a room adjacent to the entrance of the power plant, at EL. 345.0 m.

Drainage sump along with pumps shall be located at El. 300.0 m. Air conditioning room is foreseen at El. 350.20 m.

Suitable safety exits shall be provided. Other safety measures as required shall be taken during construction, operation and maintenance periods.

An electrical lift and a goods lift will also be provided in the power house building.

Here-below is a descriptive summary of all hydro-electromechanical systems foreseen in the powerhouse. Detailed and sizing values are provided in the main report.

7.3.2. Turbine

The turbines will be vertical Francis type. They will be designed for an operating range based on net heads ranging from 142 m to 220 m, which is a standard operating range for this type of turbines. Its

Net rated head (corresponding to rated discharge of 6 machines)	200.00 m
Exceptional net head (corresponding to rated discharge of 6 machines and MOL ult)	144.00 m
Net head corresponding to the rated discharge of 6 machines under MOL	164.20 m
Minimum net head (corresponding to the rated discharge of 6 machines under MOL)	170.20 m
Maximum net head	221.00 m

Turbine Basic data :	
(a) Rated Output at rated head of 200 m	206 MW
(b) Overload capacity continuous	5%
(c) Specific speed	140 rpm
(d) Rated speed	230.80 rpm

The turbine supply will include steel spiral case, stay ring, turbine runner, turbine shaft with guide bearing, shaft seal, head cover, wicket gates and operating mechanism, draft tube liner.

7.3.3. Main Inlet Valves

Main Inlet Spherical Valve (inner diameter 3.8 m) for shutting off pressure water supply from the penstock to the turbine shall be provided complete with necessary piping, control cabinet, upstream and downstream connecting pipes with companion flanges, dismantling joint, bypass, operating mechanism etc. The valve shall have two oil pressure operated working seals (one service seal and the other maintenance seal). The seals shall be of material with high resistance properties to silt erosion.

The valve shall be provided with upstream and downstream companion flanges of the full face bearing type along with necessary connecting pipe (valve inlet pipe) to match with corresponding penstock at upstream and suitable pipe for connecting with turbine distributor at the downstream of the valve.

The MIV shall be opened by oil pressure from the common OPU. It shall be designed for the safe emergency closure in case of turbine going to runaway speed (failure of governor) with the help of counterweights provided on the valve.
It shall be capable in general of closing against maximum head and flow through the valve.

7.3.4. Governor

The electro-hydraulic governor shall be of digital type with combined proportional integral and derivative function (PID) for control and regulating function and a hydraulic part acting as a power amplifying servo unit. The governor shall govern the turbine generator unit to a uniform speed free from instability and shall provide for stable operation in all stages or conditions of operation of the generating units.

7.3.5. Oil Pressure System for Governor and Turbine Inlet Valves

Each turbine shall be provided with a pr essure oil system for operation of turbine servomotors through governors and the opening and closing of MIV. The pr essure oil system shall consist of oil sump tank, oil pumping unit, oil pressure accumulator (OPU), piping valves, and fittings for switchgear for manual and automatic operation. The oil pressure unit shall have compressed air for pressurizing from central compressed system.

7.3.6. Generators

The generators shall be of the 3-phase, synchronous and of the vertical shaft type directly coupled to the Francis turbines. Each generator shall have the following characteristics:

Rated continuous output	235.3 MVA
Power factor	0.85 lagging

Frequency	50 Hz
Number of phases	3
Speed	230.77 rpm
Rated terminal voltage	15.5 kV
Terminal voltage range	± 10 per cent
Frequency range	± 3 per cent
Short circuit ratio	1.10 or more
Stator winding connection	Star (Y)
Generator earthing	Star point earthed through distribution transformer
Inertia constant (H)	3.5 MW-sec/MVA at least
Stator and rotor insulation	Class ‘F’
Bearing arrangement	Suspension type

When operating with the most unfavorable above conditions, the temperature rises of the generators shall not exceed the limits given in the IEC 60034-1 standard for the insulation class B with a maximum ambient air temperature of 40°C.

Creep detector devices, vibration detectors, monitoring of moisture in bearing oil reservoir, dynamic monitoring of air gap etc. shall also be provided in a ddition to other required instruments.

Water sprinkler system, complete with water distribution mains, headers, detecting instruments, control instruments as required, shall be provided for extinguishing the fire within the generator.

7.3.7. Static Excitation System and AVR

Static Excitation system shall have micro-process based controls. The excitation equipment shall consist of rectifier, power transformers, thyristors, field breakers with discharge resistor, field-flashing circuit, automatic voltage regulator and protection and control devices along with accessories to complete the system.

Three phase power shall be obtained through a thre e-phase, self-cooled, indoor, metal enclosed, cast-coil type transformer connected to isolated phase bus ducts.

The excitation system shall be complete with digital voltage regulator complete system for manual and automatic voltage regulation, excitation control and indication.

This excitation system shall allow the fast response necessary to assist with the stability of the HV system during disturbances.

7.3.8. Generator MV equipment

Generator MV equipment shall be provided, including six sets of 15.5kV generator phase cubicles, including the unit circuit-breakers; and six sets of 15.5kV generator neutral cubicles.

7.3.9. Step-up transformers

The transformers of each 235.3 MVA generating unit will be three single-phase transformers, each transformer unit being a 78.5 MVA single phase unit transformer.

This solution was selected due to the excessive dimensions and weight of an equivalent three-phase transformer. The weight and dimensions are limited by the load capacity of the powerhouse access bridge (75 t ons) and other access roads from the prospective transformer factories. A single-phase transformer shall be provided as spare.

Because of their rated capacity and of their location, these transformers shall be provided with a cooling system of the oil-water type, forced oil forced water (OFWF).

7.3.10. Overhead and gantry cranes

A two-bridge EOT crane each with 235 ton main hoist and 30 ton auxiliary hoist (along with lifting beam) will be provided in the machine hall.

It will be of use during erection and maintenance work of the generators and turbines. It will also be used for handling other equipment such as drainage pumps, cooling water filters, compressors, compressed air storage tanks, oil storage tanks, etc.

For these purposes, the crane will mainly be used to handle loads from both loading bays located at each side of the powerhouse, to the erection bay level. It will also be used to handle the loads from the machine hall through the hatchways to the lower elevations.

10 ton mono-rail hoists shall also be provided for auxiliary systems, at different floor levels, etc. Hatchways are foreseen for handling purposes on administrative floor, control system floor, erection bay floor, generator floor, mechanical floor 1 and mechanical floor 2.

A gantry crane of 160 ton lifting capacity on the roof of the powerhouse will be used for transformer installation and to lower the equipment into the powerhouse erection bay.

7.3.11. Raw and filtered water system

Water will be taken from the tailrace channel, to supply:

- The cooling primary loop of each unit,
- Water will be pumped from the tailrace channel, to supply the raw water header for the cooling water needs of the plant, such as heating, ventilation and air conditioning system, as well as service water system, drinking water system, etc. There are two interconnected raw water headers, one serving as main and the other as standby. The water then proceeds from the 2 x 100% pumps in the draft tube, through a s et of 2 strainers before feeding a filtered water header that supplies water for the power plant needs. Clean (drinking) water shall also be provided to the substation facilities through piping along the cable gallery.

Cooling Water System

Cooling water system required for generating units and for other requirements of station shall be provided.

A unit-wise cooling water supply system shall be foreseen with one generating unit and its three associated transformers to be treated as a unit.

The unit cooling system shall consist of both a primary and a secondary loop. The cooling primary loop of each unit is supplied through water pumped from the draft tube through a set of dedicated pumps 2 x 100% for each unit. It proceeds through a set of strainers before feeding the main exchangers of the secondary loop. It proceeds then through a set of 2 x 100% booster pumps and another set of fine mesh strainers in order to supply cooling water to the shaft seal. The booster pumps allow shaft seal watering at a sufficient pressure rate when the unit is stopped.

The secondary cooling loop, with main and standby motor driven pumps associated with each generating unit, distributes water via automatic self-cleaning strainers to the other various coolers of the turbine, generator and main transformer.

Exceptional water supply is foreseen, for emergency or maintenance case, for primary cooling system or fire-protection system, through an emergency water supply header. The water is supplied by one of the two tappings on the penstock of unit 1 and unit 6, upstream of the main inlet valve, after proceeding through a reducer and a set of 500 microns strainers which feed an emergency filtered water header.

7.3.12. Drainage and dewatering system

An automatically operating drainage system shall drain all the water discharges, outlets, returns, effluents/drainages leakages from equipment and any passage from rock surrounding the power house, etc. from power house to outside. All such water will be arranged to be led into the drainage sump, except for leakage from the transformers bay which shall proceed through a water/oil separator before being rejected into the tailrace channel.

The scheme shall consist of a set of 2 x100% submersible type drainage pumps installed over the sump, with the necessary piping, sensors, control panels, etc. The capacity of the drainage pumps shall be sufficient and lift head shall be capable of lifting water from lowest water level in drainage sump to maximum flood tailrace level through piping system. An oil-water submersible pump shall be foreseen as well.

A dewatering system shall also be included with the drainage sump acting as dewatering sump as well. A set of 2 x100% submersible type pumps shall be foreseen. The capacity of dewatering pumps shall be sufficient to empty the water in the hydraulic passage of one unit within 6 hours. Lift head shall be defined so as to be able to lift water from the lowest water level in dewatering sump to maximum flood tailrace level through related piping system and accessories.

7.3.13. Air conditioning and ventilation

The power house shall be provided with ventilation and air conditioning system as required to maintain the control room, work areas at the required level of temperature, humidity and comfort. To take extra heat that is transferred through the civil structure from outside sphere of the powerhouse or created by various kinds of equipment inside the powerhouse, a ventilation and air conditioning system is set to keep the indoor design conditions of the powerhouse mentioned below:

Location	Temperature, °C	Relative humidity, %
Generator floor	<35	<75
Turbine floor	<35	<75
Electrical auxiliary room	<35	<75
Mechanical auxiliary	<35	<75

room		
Office and meeting room	<25	<70
Central control room	<25	<70
Communication room	<25	<70
Local control room	<25	<70

The system consists of several different parts. For main powerhouse and downstream auxiliary rooms, fan coils and fresh air supply equipment are equipped to keep cool and good air quality. Fan coils are used to overcome indoor heat and humid loads, while outdoor fresh air is distributed to different areas of the powerhouse after being cooled and dried by the fresh air units, which are arranged in the air conditioning equipment room.

Cooling water for fan coils and fresh air units, which move in a closed circulation loop, is the chilled water created by several water-chilling units, and the cooling water for the water-chilling units is taken from the cooling water supply system of the turbine, in an open circulation loop. The capacity of chillers is 2x100% as cold load.

The equipment above is located in the ventilation room located at El. 350.20 m.

Offices and meeting rooms, etc. are equipped with several split air conditioners based on the cooling load. Natural ventilation is used in these areas to keep indoor air quality by opening the windows.

For the areas where the air may be contaminated, such as the oil tank room, oil refreshing room, machine workshop, several separated systems are set. These systems also serve as the emergency ventilation systems in case of fire-fighting operation.

7.3.14. Oil Handling System and Oil Treatment system

Oil handling equipment for transformer and turbine lubrication shall be foreseen and located in an oil tank room at El. 311.0 m.

Oil handling system for transformer oil will be provided with suitable piping, valves, tanks and purifiers, etc.

Oil storage tank, two clean oil tanks and two dirty oil storage tanks of equal capacity shall be provided. The storage volume of two tanks with the same function purpose shall be equal to 110% of the oil volume of one transformer. In addition, portable (mobile) type oil purifier will also be provided. The oil purification equipment for cleaning the regulating and transformer oils will be installed in the same room as the oil storage tanks. Oil purifier equipment shall be suitable for degassing, dewatering, filtering and drying oil.

Oil handling system for turbine oil will be provided with suitable piping, valves, tanks and purifiers, etc. Oil storage tank, a clean oil tank and a dirty oil storage tank both of equal capacity shall be provided. The storage volume of each tank shall be equal to 110% of the oil volume of one unit and governor. The oil purification equipment for cleaning governing and lubricating oil will be installed in the same room as the oil storage tanks.

Mobile transformer oil treatment equipment shall be foreseen:

- One set for transformers,
- One set for oil bearing and oil governor.

7.3.15. Fire detection and fire-fighting system

Fire protection, detection and alarm system for generators, transformers, powerhouse, and cables will be provided.

A fire protection system for the powerplant shall also be foreseen. It will include a wet standpipe (Hydrant) installation with fire hose cabinets including hoses and spouts at key points at each and all levels in the power station and transformer area. Portable extinguishers of appropriate type and weight are also foreseen in key areas in each and all levels of the power station and transformer area.

The fire-fighting tank supplying water to all but generators (protected by CO_2 fire-fighting system) shall be located at a platform upstream of the power plant, at EL. 430m (tentative), higher than the elevation of the transformer bay, to ensure at least 6 bars of supplied water to the deluge valves. The advantage of this system, instead of a tank located at the power plant and equipped with booster pumps at its outlet, is that water flows by gravity in case of fire, and is therefore independent of power supply to the pumps.

7.3.16. Electrical Auxiliaries

AC Systems

The power supplies for the power station AC auxiliaries shall be provided by two suitably rated 15.5kV/11kV station transformers. These dry resin type transformers located on the upper floor at El.345.00 shall be connected to one 11kV auxiliary switchboard used to distribute the auxiliary power within the scheme. Each of these transformers shall satisfy the power requirements of the all the ancillaries in the powerhouse, substation, intakes and dam works.

Standby Diesel sets shall permit the black start and the emergency operation if the grid supply fails. Each Emergency Diesel generator shall be of sufficient capacity to provide power to operate the station drainage pumps, to start one generating unit and also to meet the other necessary power requirements.

DC Systems

The direct current system shall provide 220V DC power for the protection and lower level controls. The UPS shall provide power for the microprocessor based control system and communications.

The DC supply system for the powerhouse and the HV substation is completely redundant. It shall comprise two station batteries with two battery-chargers on duty and two battery-chargers on standby, two DC distribution boards, local subsidiary switchboards and two uninterruptible power systems (UPS). A discharge-resistor unit shall also be supplied for battery maintenance.

7.3.17. Supervisory, control and data acquisition system

A supervisory control and data acquisition system (SCADA System) in BUDHI GANDAKI HPP shall be provided to supervise and control:

- Generating units and the associated equipment. Part of the equipment may be controlled by a local and specific system such as the speed governors and the excitation systems. This equipment is connected to the SCADA system for general supervision and control.
- AC and DC feeding facilities, including transformers and MV and LV distribution boards.

- Upstream water intakes including the water level measurements and the AC and DC auxiliaries.
- Common equipment of the scheme such as:

  – water supply and cooling system,
  – lighting equipment,
  – ventilation and air conditioning system,
  – drainage and dewatering systems,
  – compressed air system,
  – communication system,
  – fire detection and fighting systems.

The supervising duties of the BUDHI GANDAKI HPP shall be carried out by the operator stations located in the control room.

Each generating unit shall be equipped with its own unit control and protection system. For each unit, the system’s boards shall be located at the machine hall floor in face of it. Each unit shall be designed to operate entirely independent of each other.

Manual control of the unit shall be possible from unit control boards (UCBs), whereas automatic control of the units will be carried out at main control room. Manual as well as automatic control of unit will be carried out by processing the necessary control signals from turbine, generator, transformer, switchgear and various auxiliaries.

7.3.18. Other auxiliary systems

Other following auxiliaries system shall be provided in the powerhouse as under:

- Hydraulic measurement system (upstream water level, water level downstream the intake stoplogs and emergency gates, water level downstream the spillway service gate and/or stoplogs, water level measurement in each turbine draft tube, of tailwater, turbine flow by a multiple path ultrasonic flow measurement, etc.),
- Outdoor and indoor lighting system shall be provided for the dam, gate shaft area, powerhouse, 400kV GIS room and pothead yard, powerhouse building, access

8. DESCRIPTION OF THE WORKS – POTYARD AND TRANSMISSION LINES

8.1. HV Cable gallery

A gallery shall connect the power house to the GIS building at its basement: the gallery is comprised of two compartments: a) 400kV cables, b) other cables.

The gallery shall be constructed in reinforced concrete; to this extent, special care shall be given so that the re-bars constituting the armature be placed so as NOT to form closed steel loops around the compartment accommodating the HV cables; the same precaution shall be also applied for the adjacent compartment.

The gallery floor shall be provided with drainage gutters at both sides allowing for drainage of infiltration or rainwaters down to convenient drain pits; 1kN capacity lifting hooks shall be anchored every 5.0m in gallery ceiling to ease for the installation of HV power cables.

Where reaching the building boundary, the gallery shall split into two branches: one straightforward to GIS bays, one at left-hand side heading to the nearest GIS unit incoming bay.

Galleries will be ventilated in such a way so as to prevent the inordinate temperature rise of the 230/400kV cables: the ventilation shall be by natural air draft incoming at either powerhouse side or GIS building side and exiting through ventilation stacks placed at convenient locations along the gallery.

8.2. GIS

The GIS shall be arranged in five major back-to-back bays, each set up in a breaker-and-a half design and being connected to two main busbars. The bays will be connected to:

- Four (4) transmission line feeders
- Six (6) generator step-up transformer feeders

Each busbar will be provided with its individual voltage measurement cell.

The gas insulated switchgear substation will be located at ground floor of substation main building.

All of the five three-phase GIS bays will have their longitudinal axis in the direction of the outgoing transmission lines.

Under such arrangement, a space of 24m width x 27m length inside the building is to be provided for the installation of the GIS; the width being measured along the direction of the outgoing transmission lines whereas the length is counted perpendicular to this reference.

Each incoming and outgoing circuit of either generator unit or overhead lines will be connected to the busbars and operated in a manner that will allow individual circuit isolation and supply. The spacing between GIS bay units shall be set to allow for its safe operation and maintenance.

Special care is taken so as to rationalize the bay configuration leading to two types of 400kV GIS bay: unit-to-unit, and unit-to-line.

8.3. Switchyard

A flat ground area of approximately 115m long and 34m wide will be required for accommodating the lines terminal portal and installing the 400kV yard equipment and the busbars leading to the GIS : this switchyard shall be adjacent to GIS building at mountain flank side.

Being close to the mountain side, the arrangement of the switchyard is considered while taking into account:

- the eventuality of rock falls;
- the ground clearance of the overhead transmission lines.

For these reasons, the structures and equipment of the switchyard are located as far as possible from the mountain foot. As general precautions, appropriate means to prevent either rock falls or landslide shall be implemented at mountain side; ditches (along the switchyard fence at mountain side), drainage trenches shall be provided to avoid either flooding or rainwater accumulation over the yard.

8.4. Technical building

Within the 400kV substation, a technical building shall house a 400V switchboard directly connected to the powerhouse 400V network through the station services board.

8.5. Mechanical auxiliary systems

Fire protection, detection and alarm system for substation will be provided, as well as drainage and HVAC system.

A crane shall be provided in GIS building for the handling of GIS equipment.

8.6. Transmission lines

The power generated from the Budhi Gandaki hydroelectric project is envisaged to be evacuated through two 400 kV double circuit transmission lines from the BGHEP potyard to two proposed grid interconnection points New Hetauda substation and proposed Naubise substation. At present, the ACSR Moose (Quad bundle per phase) conductor is proposed for the proposed transmission lines.

The maximum power carrying capacity of each circuit is approximately 600 MW therefore each of the proposed HV lines has a total capacity of 1200 MW. The concept of having two power evacuation HV lines able to transport individually the full capacity of BGHEP provides a considerable safety in the energy supply to the INPS.

A Transmission Line Corridor study was carried out to determine the suitable route alignment for carrying out detail route survey of the two 400 kV double circuit transmission lines, that is, from the potyard of Budhi Gandaki Hydroelectric Project (BG HPP) to the proposed 400 kV New Hetauda Substation and proposed Naubise substation.

The transmission lines potential corridors were selected with the aim of minimizing the lengths and environmental and social impacts.

The multi-criteria analysis was carried out for the identification and selection of the best 400 kV transmission line route for both Hetauda and Naubise line. The total estimate length of the transmission lines is 58.7km for HETAUDA and 40.3km for NAUBISE.

The detail route alignment survey have been carried out for the best transmission line routes of both Hetauda and Naubise lines in order to pick the topographical features along the transmission line alignment such as r iver crossings, road crossings, power line crossings, forest areas, manmade features, etc and their details. And the concrete pillars are established at each angle point location.

The following figures Figure 8-1 and F igure 8-2 present the final route alignment for each transmission lines (Hetauda and Naubise).

Figure 8-1: TL 400kV BG HPP – Hetauda substation - General layout plan

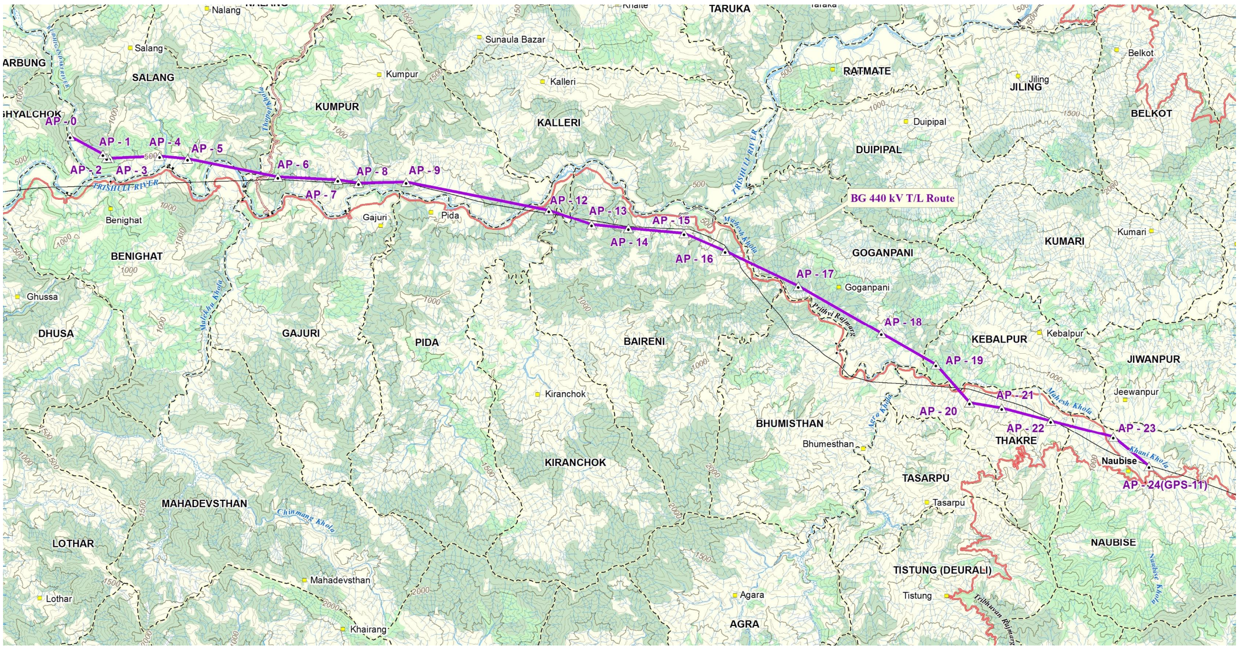


Figure 8-2: TL 400 kV – BG HPP - Naubise substation - General layout plan

8.7. Grid Impact studies

The Grid Impact Study consists in analyzing the impact and the power evacuation of Budhi Gandaki HPP to the rest of power grid, by modeling and simulating Nepalese electrical network for horizon 2025. Different analyses such as load flow, short circuit or transient stability have been carried out, in order to understand the behavior of the power grid in different circumstances and to point out possible problems and solutions.

As software tool, Cyme has been used in its 7.0 version. This software is widely distributed in the world and allows studying networks with up to thousands of buses and branches, and control of active power exchange between regions.

To sum up, different scenarios of the power grid, such as peak load in wet season, peak load in dry season and off-peak load in dry season, have been studied for horizon 2025. The model has been performed for various options and takes into account possible routes of transferring power. We also verify that voltages remain in the voltage range imposed by the grid code while keeping the power plants in their acceptable reactive power operating ranges, and we point out possible overload phenomenon. Different short circuit currents have been calculated according to the IEC 60909 standards. Transient stability analysis allows us to study the impact of several contingencies that may occur in the grid.

This study also demonstrate that the power transmission system connecting Budhi Gandaki HPP to Naubise and Hetauda is well designed in terms of capacitance compensation, transmission lines or power transformers, and that the criteria N-1 is satisfied (loss of one Unit or loss of one transmission line circuit without destabilizing the INPS).

As far as the INPS is concerned significant reinforcements will be required on the network latest by 2024. However this is considered as usual for the interconnection of a project of the size of Budhi Gandaki.

9. ENVIRONMENTAL AND SOCIAL CONTEXT

9.1. General

The Dhading and Gorkha districts (Figure 9-1) have a relatively low (110 persons/km^2) density of population as compared to other hill districts (186 person/km^2) but also compared to the national average density (180 person/sq km) according to the 2011 census.

Agriculture is the main bases of the economy and livelihood of the project districts people. However, remittance income, small business and trades are also contributing in the household income in the recent years. The project districts have a total land area of 553 487 hectare of which 20% is cultivable. More than one third of the land area (34%) is unusable and occupied by river, rock, road, residence area, land slide, etc. Forest area occupies one third of the land area. Of the total cultivated land only 40% is irrigated.
Major agriculture production of project districts is cereal crops (paddy, maize, millet and wheat), oilseed and pulses. However, these days the districts are famous for vegetable production which is supplied to the capital city and other major town areas. Livestock is an important component of farming system in the project districts and regarded as one of the major assets of farm household. The districts are producing significant volume of livestock products such as meat, milk, egg and wool.

More than 2 700 small and cottage industries are registered in the two project districts. Of the total industries, 91% are small in scale and 62% are service type.

Figure 9-1: Affected VDCs in Gorkha and Dhading districts

9.2. Environmental and Social Impact Assessment

9.2.1. Status of the studies

The ToR and Scoping Documents submitted for approval to GoN in May 2014 have been subsequently approved in April 2015. The Public Consultation and Disclosure Plan (PCDP) has been submitted in March 2014 and is since then regularly updated. The last revision of the PCDP has been submitted in October2014. The census survey has been conducted in Dhading and Ghorka Districts and completed in January 2015. The analysis and interpretation of the data collected has been completed in June 2015.

The Environmental and Social Impact Assessment was submitted in November 2015 for review by BGHPDC before undergoing final public consultation.

9.2.2. Environmental costs

Table 9-1 provides a summary of environmental and social costs.

The total environmental cost of the project is estimated at **NRs. 61,206.45 million** which is about 24% of the total Project cost. The details are provided in the table below.

S.No.	Cost Items	NRs
A	Environmental Mitigation Physical/Chemical Environment	In built in construction contract
B	Environmental Mitigation Biological Environment	1.569.848.970
C	Environmental Mitigation Social and Cultural Environments (LARRAP Cost)	55.827.618.993
D	Environmental Monitoring costs	30.435.000
E	Environmental Audit cost (MoSTE)	2.500.000
F	***Total Environmental Mitigation / Monitoring and Auditing***	***57.430.402.963***
G	Contingency (5% of F)	2.871.520.148
H	Support cost for environmental and social monitoring management (1.5% of F+G)	904.528.847
	Total EMP costs (F+G+H)	**61.206.451.958**

Table 9-1: Environmental and Social Mitigation-Total cost estimate

The details of the cost corresponding to the LARRAP - Land Acquisition, Rehabilitation and Resettlement Action Plan (line C in Table 9-1 above) is given in the following Table 9-2.

S.No.	Descriptions of Cost	Total Cost (NRs)
I.	**Compensation of Land and Land Based Assets/ Facilities, consisting of:**	**37,686,962,529**
I.1	Compensation for land	32,064,962,529
I.2	Compensation of structures	5,284,910,000
I.3	Compensation of trees	306,954,000
I.4	Compensation for utilities	30,136,000
II.	**Resettlement and Rehabilitation Assistance, consisting of:**	**8,232,783,359**
II.1	Land for resettlement	5,397,603,359
II.2	Resettlement Site Plan	3,710,000
II.3	Infrastructure development	2,535,000,000
II.4	Cash allowances, total	1,220,780,000
II.5	Compensation for agricultural loss	384,037,000
II.6	Relocation of cultural heritage	296,470,000
III	**Livelihood Restoration, consisting of:**	**1,996,275,000**
III.1	Trainings	484,205,000
III.2	Aquaculture support (technical and materials)	12,070,000
III.3	Livelihood Restoration Trust Fund	1,500,000,000
IV	**Community Development Plans, consisting of:**	**7,911,598,105**
IV.1	Budhi Gandaki Ring Road Study	4,460,000
IV.2	Land acquisition for the road development	4,238,118,193
IV.3	Road development	3,250,519,912
IV.4	Community Development Planning and Studies	418,500,000
	Total of LARRAP /IPVCDP/LRP and CDP	**55,827,618,993**

Table 9-2: Details of LARRAP total cost

9.2.3. *Land Use under Reservoir Acquisition Area*

The BGHEP reservoir Full Supply Level (FSL) is 540m masl. The surface area of land to be flooded by the reservoir is estimated to be 63 km2. An additional 5m buffer is added to this FSL level to minimize the risks of potential flood and reservoir rim failure, leading to a total surface area of 6788 ha (68 km2). Classification of the land category in the LiDAR ortho-photomaps reveals the following land uses within the BGHEP reservoir.

Land use Type	Area (ha)
Bush	637
Forest	1765
Grass	222
Barren Land	3
Cultivation / settlement	3183
Dense Settlement	0.8
Nursery	1.3
Orchard	19
Cliff	4
Sand	562
Water Body	390
Total	**6788**

Table 9-3: Land Use BGHEP Reservoir

A total of 3424 ha land is under agriculture and settlement, which is about 50% of the total land area required for the BGHEP reservoir. Except the settlements of Arughat in Aaruchanuate VDC and Bisal Bazar in Salyantar VDC rest of the other settlements in the reservoir area have a land based livelihood.

9.2.4. *Displaced Households and Persons – BG HPP Reservoir*

Based on the socio-economic census survey, the estimates of number of households to be economically and/or physically displaced, and the indi rect estimate of economically and/or physically displaced persons, are as follows:

Displacement / impact Type	No of Households	Persons
Physically impacted	3 560	20 260
Economically impacted	4 557	25 351
Total Physical and Economic Displacement	**8 117**	**45 611**

Table 9-4: Displaced Households and Persons – BGHEP Reservoir

9.2.5. *Displacement of Infrastructures – BGHEP Reservoir*

Reservoir inundation also displaces a number of educational, service institutions, temples/shrines, cremation sites and access facilities particularly motorable roads, suspension bridges, and motorable bridges, which are not only used by th e physically

displaced persons but also by the upland residents of the region. These infrastructures need re-establishment for both the displaced persons in the relocation sites but also to the upland residents. The **Table 9-5** below summarizes the displaced infrastructures on account of reservoir inundation.

Displaced Infrastructure	Nos
Public Educational Institutions	23
Other service infrastructures (health posts, police post, post office, community halls etc)	64
Temples and Shrines	74
Motorable Road	132 km
Motorable Bridges	6
Suspension Bridges	30
Cremation Sites	44

Source: Field Survey, 2014

Table 9-5: Displaced Infrastructures – BGHEP Reservoir

10. DOWNSTREAM IMPACTS

Dam break wave analysis

The study of the dam break wave propagation of BG HPP has determined the flooded areas, and quantified the characteristics of the dam break wave: water heights, flow velocities and propagation speed. Based on these characteristics, the involved potential damages were preliminary identified along the Trishuli and Narayani rivers.

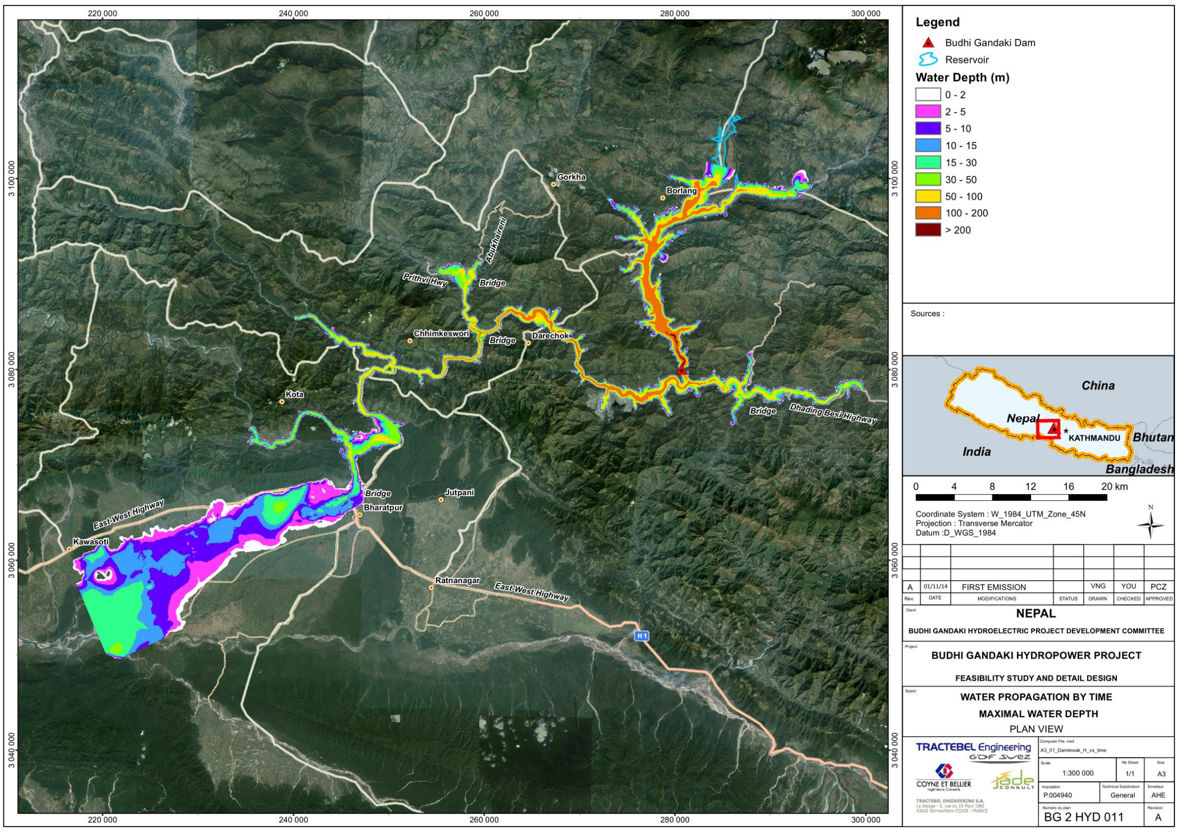


Figure 10-1: Dam break analysis – maximal water depths

(See Vol.17 - BG-3-1-HYD-004 to 013)

The surge wave created by the dam break is about 150m high at the confluence of the Budhi Gandaki and the Trishuli river and gets attenuated after propagation. The surge wave remains however in the range of 20m at the Nepal-India border, about 8 hours after the dam break.

Modified mean monthly discharges downstream of BG HPP

Modified hydrograms and mean monthly discharges have been computed at different location along the Trishuli and the Narayani rivers. See **Figure 10-2**. As illustrated in the following **Table 10-1**, **Table 10-2** and **Table 10-3**, **the mean monthly discharges in the dry season period from December to May are significantly increased.**

Globally, in terms of monthly average discharge, BG HPP will have a positive effect on the existing or planned Irrigation Projects and Hydropower Plants located downstream in the Trishuli river and the Narayani river.

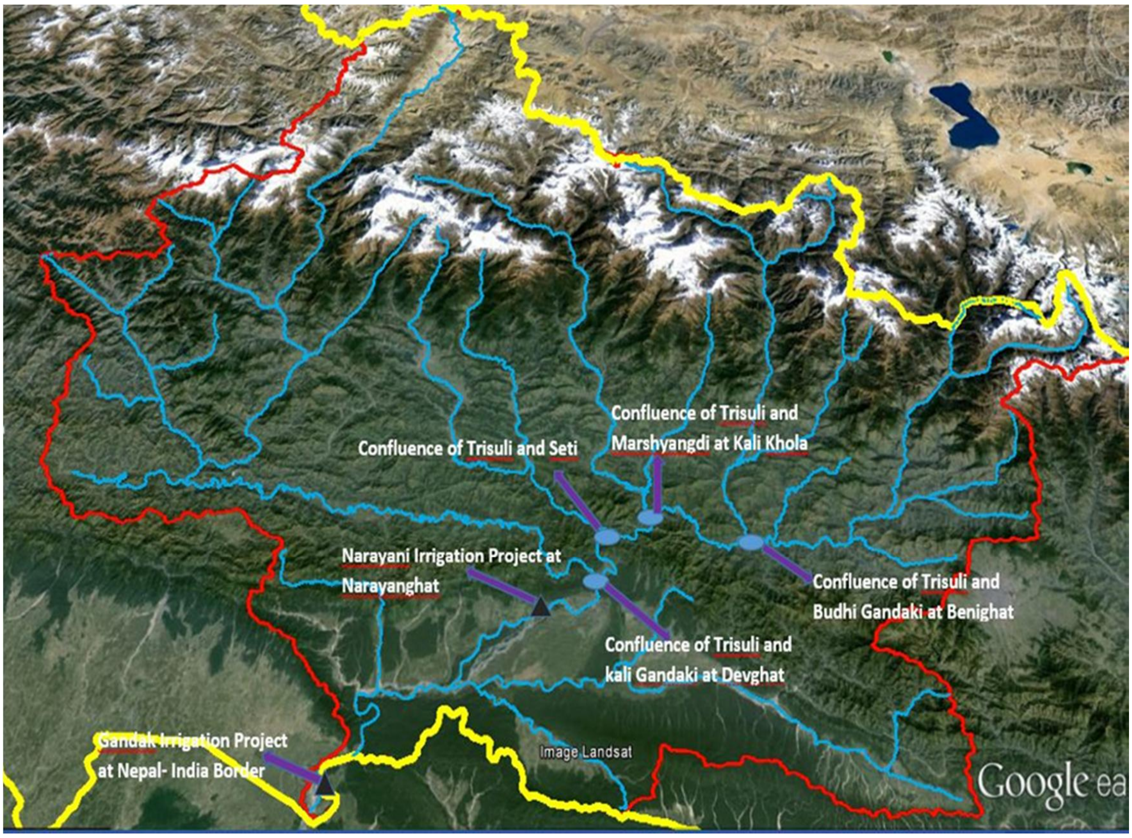
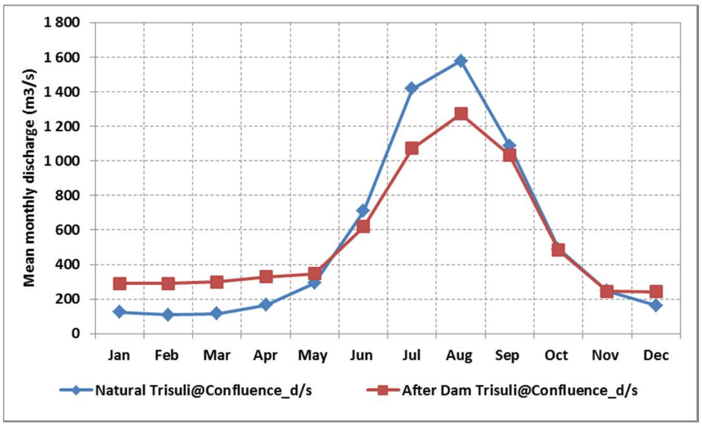
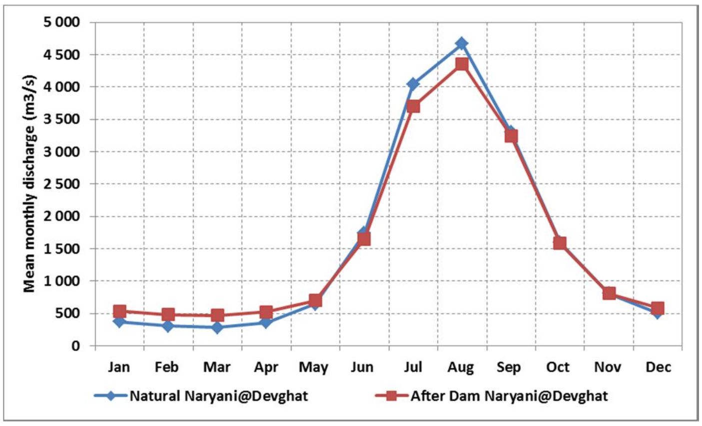


Figure 10-2: Narayani river basin



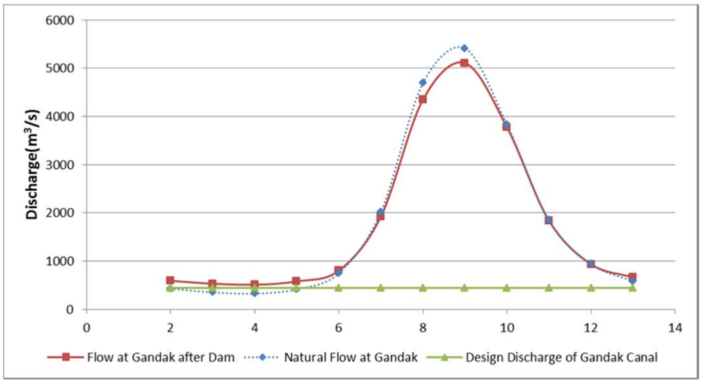
	Natural	After BG Construction	%
	Trishuli@ Confluence d/s	Trishuli@ Confluence_ d/s	
Catchment Area (A) (km²)	11628	11628	
Jan	126	290	+130%
Feb	110	290	+163%
Mar	116	300	+158%
Apr	165	330	+100%
May	293	347	+18%
Jun	710	618	-13%
Jul	1418	1072	-24%
Aug	1579	1271	-20%
Sep	1087	1033	-5%
Oct	490	483	-1%
Nov	248	246	0%
Dec	163	243	+49%

Table 10-1: Modified Trishuli Hydrogram at the confluence Budhi Gandaki – Trishuli after implementation of BG HPP Project



	Natural	After BG Construction	%
	Naryani@ Devghat	Naryani@ Devghat	
Catchment Area (A) (km²)	31714	31714	
Jan	369	533	+44%
Feb	303	482	+59%
Mar	281	464	+65%
Apr	358	522	+46%
May	645	698	+8,2%
Jun	1736	1645	-5%
Jul	4044	3698	-9%
Aug	4668	4361	-7%
Sep	3302	3248	-2%
Oct	1590	1583	0%
Nov	808	806	0%
Dec	501	580	+16%

Table 10-2: Modified Naranyani Hydrogram at Devghat after implementation of BG HPP Project



Month	Natural flow at Gandak	Flow at Gandak after BGHEP Dam	%
Jan	428	593	+39%
Feb	351	531	+51%
Mar	326	509	+56%
Apr	415	579	+40%
May	748	802	+7%
Jun	2014	1923	-5%
Jul	4691	4345	-7%
Aug	5415	5108	-6%
Sep	3830	3776	-1%
Oct	1845	1838	0%
Nov	937	935	0%
Dec	581	661	+14%

Table 10-3: Modified Naranyani Hydrogram at Gandak Barrage after implementation of BG HPP Project

Modified hourly discharges downstream of BG HPP

Additional benefits on hydro power plant

An analysis of the benefit generated by the seasonal regulation of BG HPP reservoir on the existing and projected hydro power plants located downstream of BG HPP has been conducted. The results in term of additional energy production and revenues is presented in the Table 10-4 below

Power Plant	Capacity	Mean annual energy	Additionnal mean annual energy			Additionnal mean benefits	Comments
			Dry season	Wet season	Total		
	MW	GWh	GWh	GWh	GWh	MUSD	
Gandak Barrage	15	27,2	4,02	0,11	4,13	0,35	In operation, commissioned in 1979
Super Trishuli HPP	100	405,8	53,1	6,7	59,8	3,6	License for BOOT ; Feasibility study in 2014
Sapta Gandaki HPP	225	1485,8	162,7	62,6	225,3	13,5	Feasibility study by JICA in 1981 for GoN
TOTAL		1918,8	219,82	69,41	289,23	17,45	

Table 10-4: Additional benefits for hydro power plants D/S of BG HPP

Downstream surges in the Trishuli river due to BG HPP operation.

The Budhi Gandaki HPP is a storage hydropower plant Project designed to produce peak energy during the daily peak electric energy consumption time demanded by the Nepal interconnected network. The requirement of peak energy is particularly strong during the winter months when the other interconnected hydropower plants from Nepal which are mostly runoff river schemes, are suffering from low water river discharges and are not able to produce at their full installed capacity.

The Budhi Gandaki river joins the Trishuli river at 2 km distance downstream of the Budhi Gandaki HPP. In the winter period the discharge of the Trishuli river is around 50 to 100 m^3/s. The Trishuli flow regime variation will be very marked in the dry season and will generate i) a safety hazard for the population downstream of Budhi Gandaki and along the Trishuli and, ii) limitations and/or additional costs in the sizing and operation of downstream irrigation facilities and projected hydropower plant along the Trishuli river.

In this context a specific study has been carried out to analyze the downstream propagation of the daily surge generated by the operation of BG HPP.

Several realistic scenarios have been envisaged to determine the output hydrogram generated by BG HPP at that will propagate downstream in the Trishuli river.

- Satisfying the projected peak demand at BG HPP commissioning period in 2023,
- Satisfying the projected peak demand that will occur during the lifetime period of BG HPP,
- Compensation of a network partial of total failure (black-start or compensation of the failure of one of the power production plants feeding the INPS).

The first scenario is not a governing scenario for the Trishuli maximum downstream surge.

The second scenario is more critical since it takes into consideration the expected future load and energy demand of the INPS. The evaluation of the peak demand in 2035 ranges between 6 000 MW and 10 000 MW, according to the average and high load forecast scenarios. The available power at BG HPP represents between 12% and 20% of this demand. Comparing the 1 200 MW capacity of BG HPP with the projected demand, it is clear that the scheme in itself will not be able to fulfil the total peak demand of the INPS, even more so if we consider the potential possibilities of energy exchanges with neighbour countries. In this context, the BG HPP will be requested to start production and reach its rated capacity as quickly as possible, together with other energy production schemes, to satisfy the whole peak demand.

This situation is typical in many countries using hydroelectric energy as the main source to fulfil the peak energy demands (such as France), where several hydroelectric schemes are requested to start within a very short time at the peak demand period.

The third scenario involve 2 sub-scenarios: The black start is an accidental situation where the Budhi Gandaki scheme will have to compensate the total or partial failure of the INPS. A total failure of a national network is a rare event with low occurrence probability but it is recalled that it has happened already in developed countries. In case of a partial failure of the energy supply structures (power plants or HV lines), the BG HPP will be requested in priority since it is able to start quickly, and provide a significant power to the network. In this case, the quickest start is required, because, to regulate and stabilize the network, it is crucial to equilibrate at best and in the shortest time the energy demand and the production.

The second parameter to take into consideration is the mechanical constraints on the starting time. Given the fact that BG HPP will produce a significant part of the energy on the country in its commissioning period, the frequency regulation of the network will be a strong constraint on the modes of energy production, especially at peak production. The hydroelectric power plants are generally requested to start a quick as possible, and are designed accordingly. Hydroelectric power plants associated with long tunnels are not able to provide this reactivity. The particularity of BG HPP is its very compact layout with waterways upstream of powerhouse short enough to overcome transient’s phenomena that may constraint the starting time. The mechanical minimum starting time is about 1 minute, which allows reaching the rated discharge for each unit simultaneously within 1 minute of total time.

The summary of these scenarios analysis allows identifying clearly the fact that the quick start is the only scenario that is determining in terms of downstream impacts, and have to be considered for the output hydrogram of the powerhouse, since it covers the largest period of the scheme lifetime in peak energy production, the possible requests of stabilisation of the network in situations of partial failure of the energy-production facilities in the country, and the potential energy trade requests with interconnected countries. Both usual and some accidental situations are covered by this scenario. Moreover, only a scenario of a quick start within a peak energy production is determining, since that, whatever the starting time chosen, the peak discharge remains the guiding parameters which controls the propagation phenomenon.

The output hydrogram has been built accordingly, in such way that the rated discharge of the powerhouse is reached in 1 minute of time interval. The BG HPP rated discharge is 672 m3/s for a 1 200 MW power plant will be released during approx. 6 to 10 hours per day whereas the rest of the day the plant will be on standby or releasing a marginal discharge to ensure a minimum base energy production for regional or national energy requirements.

Even if the daily energy production last for 6 to 10 hours, the modelled BG HPP output hydrogram is defined for a time of 1 hour, because there is no need to simulate a such long period for hydraulic downstream impact studies.

The **Figure 10-3** presents the 11 sections where the propagated surge generated by BG HPP has been evaluated.

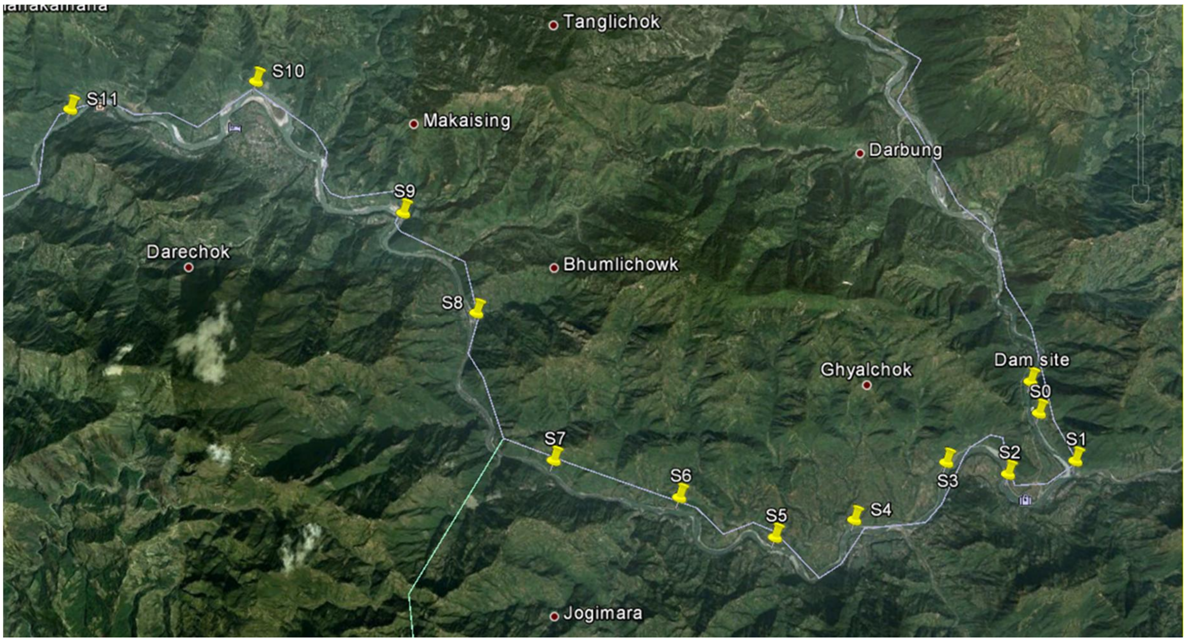


Figure 10-3: Trishuli river – sections for BG HPP surge propagation analysis

The Figure 10-4 and the Table 10-5 provides the details of the surge propagation along the Trishuli river.

It is worth mentioning that the river surge at 10 km (section S6) downstream of BG HPP arrives after 1 hour and 50 minutes, exceeds a height of 5m which is rising in 30 minutes only.

At 25 km (section S11) the surge gets attenuated arriving after 4 hours with a height of 2,4 m rising in 1 hour.

This surge definitely creates a safety hazard for the populations downstream over a distance of about 30km. A strict control of the Trishuli river banks is not practical and difficult to implement. Tractebel Engineering has recommended to create a compensation or re-regulation reservoir able to avoid or reduce the surge height and the corresponding propagation length.

The scope of TRACTEBEL Engineering does not include the study of the compensation reservoir within the present Contract Agreement.

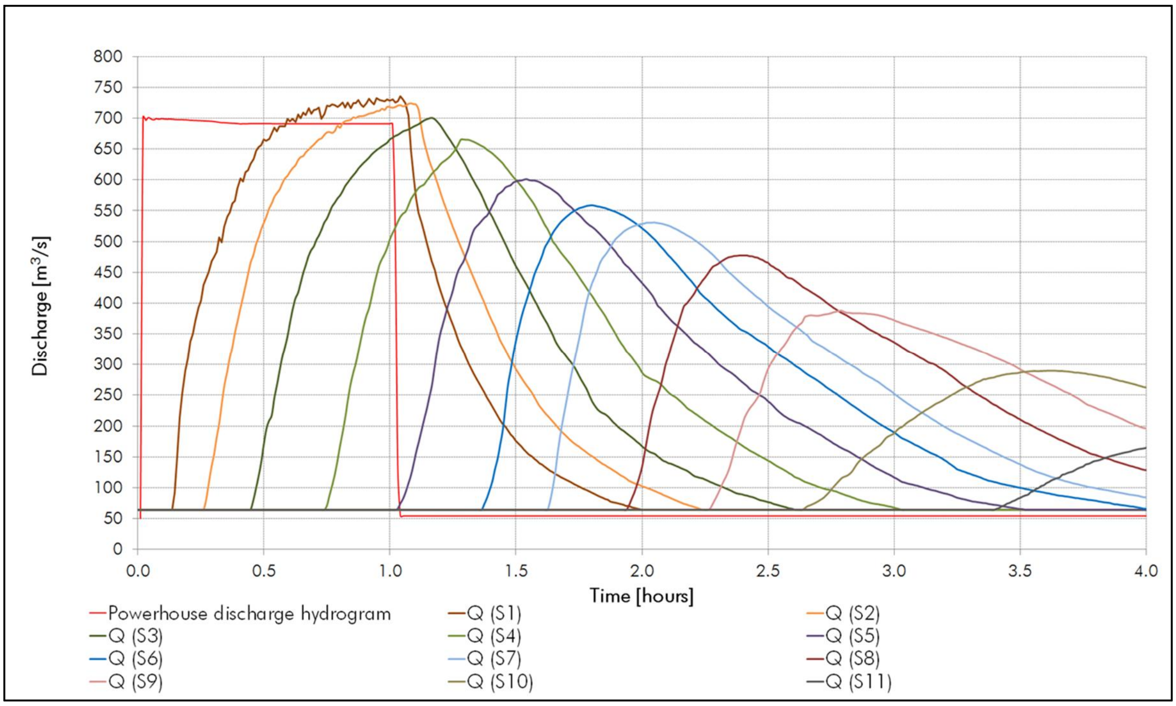


Figure 10-4: BG HPP peak hydrogram propagation along the Trishuli river

Sections	Distance	Cumulative distance	Peak discharge	Maximum wave height	Time of peak arrival	Starting time of rising phase	Duration of rising phase
[-]	[m]	[m]	[m³/s]	[m]	[h]	[h]	[h]
S0	0	0	672	6.3	0.02	0.00	0.02
S1	1 353	1 353	736	4.5	0.89	0.13	0.75
S2	1 225	2 578	724	4.6	1.09	0.25	0.84
S3	1 290	3 868	701	5.4	1.18	0.45	0.73
S4	2 261	6 129	665	4.2	1.35	0.74	0.61
S5	1 628	7 757	601	4.6	1.64	1.04	0.59
S6	1 836	9 593	559	5.1	1.84	1.34	0.51
S7	2 583	12 176	531	4.9	2.09	1.59	0.50
S8	3 301	15 476	477	3.1	2.54	2.03	0.51
S9	2 490	17 967	388	1.5	3.21	2.41	0.80
S10	3 394	21 360	290	1.7	3.70	2.73	0.96
S11	3 908	25 268	213	2.4	4.17	3.13	1.04

Table 10-5: BG HPP peak hydrogram propagation – details

11. CONSTRUCTION SCHEDULE AND MANPOWER REQUIREMENT

11.1. Construction Schedule

Construction Schedule of the Budhi Gandaki Project considers the possibility of early start of the Commissioning of all Units at the Ultimate Minimum Operating Level (MOLult.) El.467 in the year 2024.

Detailed Construction Schedule presenting the Main Structures, Procedure of the Impounding, Commissioning of the Units and their respective activities, sequences and constraints are given in the draft Detail Design Report Vol.15- Chapter 4.- Implementation and Construction Schedule.

Construction Planning proposes that the construction works are divided in three Lots:

- LOT n°1 - Preconstruction Preparatory Works
- LOT n°2 - River Diversion, Double Curvature Arch Dam, Tail Water Dam, and Impounding of the Reservoir
- LOT n°3 – Waterways, Power Plant, and Transmission Lines

The purpose of this works distribution enables:

- **Start, at an early stage, i.e. November 2016** the construction of the Preparatory Works under LOT n°1 which are on the critical path without expecting the award of the Main Works under LOT n°2 and LOT n°3. The completion of the Permanent Facilities Construction is the precedence, constraint, for the starting of the construction works of the Contractors LOT n°2 and LOT n°3.
- The Client to Secure the Financing for LOT n°1, LOT n°2 and LOT n°3.
- The completion of the Procedures of Prequalification, Bid Consultation, Bid Evaluation, Negotiations and Contract award for Lot 1, Lot 2 and Lot 3

The Summary of the Construction Schedule shown in – Figure Figure 11-1: Summary of Construction Schedule 1/4

; Figure 11-2 Figure 11-3 and Figure 11-4 below, presents the Works which are on the Critical Path:

- Permanent Facilities Construction
- Diversion Works
- Main Dam Construction
- Commissioning of all Units at the El.467.00

The total construction time is estimated to **7 years and 10 months with full commercial operation of the plant in July 2024.**

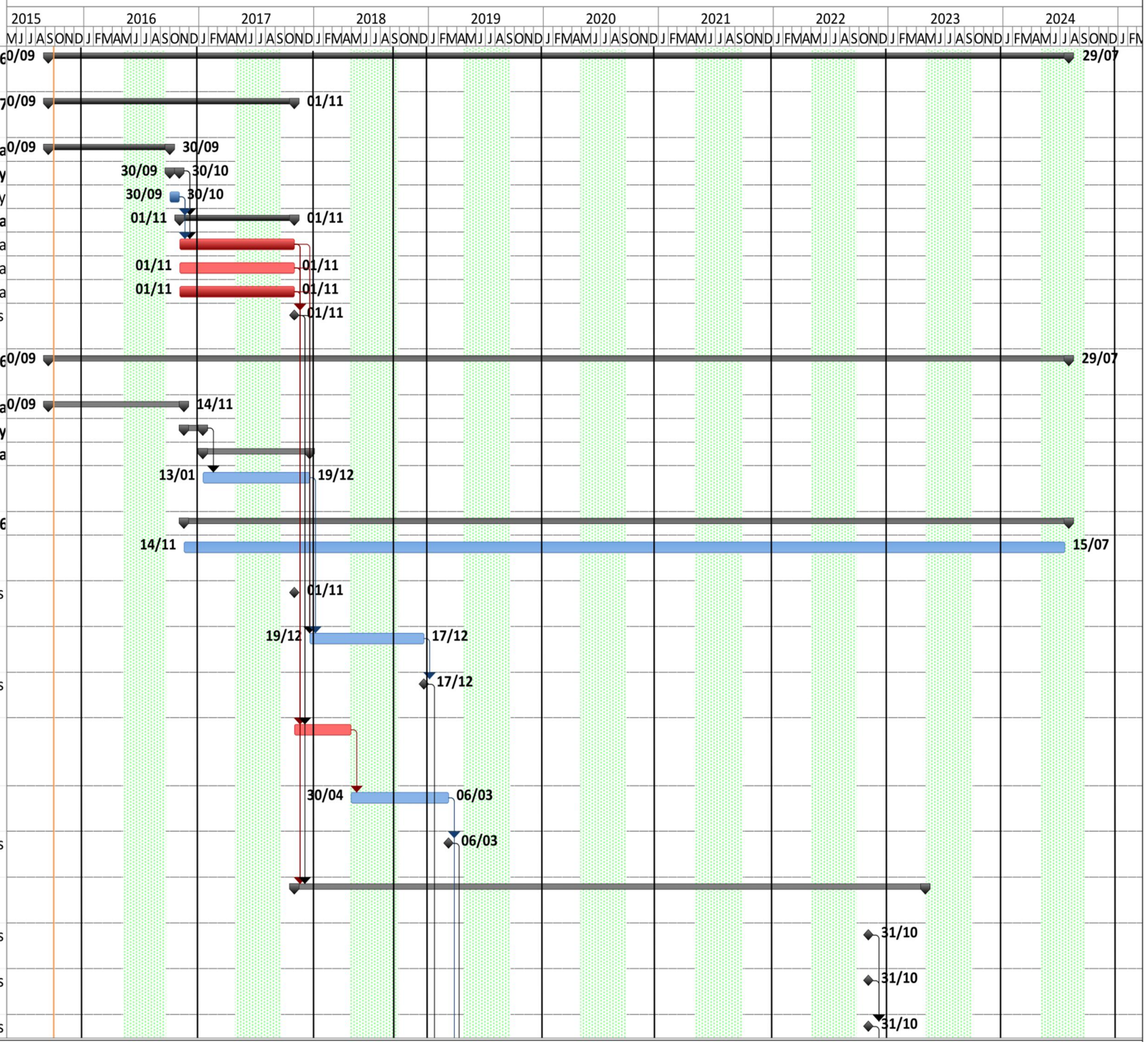
To be noted that the construction schedule is linked with the seasons and river hydraulics. Therefore any significant offset of the Start of Construction date is likely to offset the completion date by one year.

The above mentioned report on the Implementation and Construction Schedule gives the examples which show some Dams similar to Budhi Gandaki Dam, with respect to height,

crest length and complexity of the Bottom Outlets and Spillways incorporated in the Dam body which were done in the similar Construction time as proposed by presented Work Schedule.

Figure 11-1: Summary of Construction Schedule 1/4

ID	Ta Mo	Text1	Task Name	Duratio
1			**Budhi Gandaki**	**3244.6 days**
2		**1.**	**Lot - 1 - Preparatory Works**	**782.67 days**
3			**Procedures preceding Lot 1 Contract Award**	**386 da**
10		**1.7**	**Lot 1 - Contract Award**	**30 day**
11		1.8	Bank Guaranties	30 day
12			**Permanent Facilities Construction**	**365 da**
13		1.9	Permanent Camp Facility	365 da
14		1.10	Permanent Roads	365 da
15		1.11	Permanent Bridge	365 da
16		1.12	MS1-1-Permanent Camp&Roads&Bridge - Completed	0 days
17		**2.**	**Lot - 2 - Dam & Appurtenant Structures**	**3244.6 days**
18			**Procedures preceding Lot 1 Contract Award**	**431 da**
25		**2.7**	**Lot 2 - Contract Award**	**60 day**
27			**Mobilization**	**340 da**
28		2.9	Mobilization	340 days
29			**Construction Engineering & Drawings**	**2813.6**
30		2.10	Construction Engineering & Drawings	2800 days
31		2.11	**MS1-1-Permanent Camp&Roads&Bridge - Completed**	0 days
32		2.12	Platform -El.610 & El.580 & El.542	363 days
33		2.13	MS2-1-Platform-El.610 & El.580 & El.542-completed	0 days
34		2.14	Platform PH-El.345.00&El.326.00-Excavation-Zone Diversion Tunnel Outlet&Power House	180 days
35		2.15	Platform PH-El.345.00-Excavation-Zone Power House	310 days
36		2.16	MS2-2-Platform PH-El.345.00-Excavation-Zone Power House-Completed	0 days
37		**2.17**	**Diversion Works&TWD&Tailrace Channel**	**2006 days**
80		2.19	KD2-6-Secure of construction material due to closing of Acces to U/S Borrow Areas	0 days
81		2.20	KD2-7-U/S Cofferdam crest to be localy lowered for maintaining the Reservoir at El.355	0 days
82		2.21	MS2-4-Diversion Tunnels - Permanent Closure	0 days

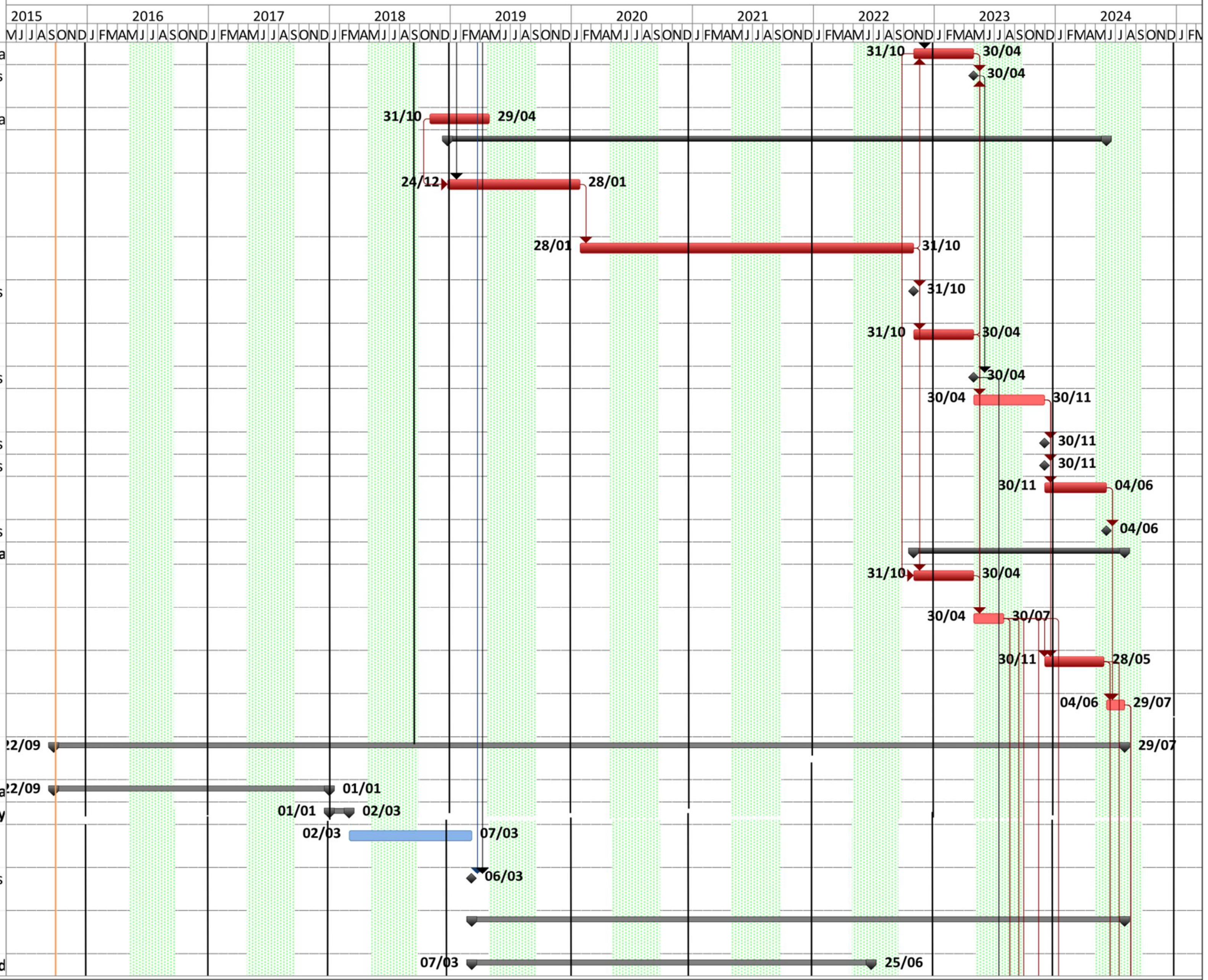


Task		Project Summary		Inactive Milestone		Manual Summary Rollup		Deadline	
Split		External Tasks		Inactive Summary		Manual Summary		Critical	
Milestone		External Milestone		Manual Task		Start-only		Critical Split	
Summary		Inactive Task		Duration-only		Finish-only		Progress	

Page 1

Figure 11-2 - Summary of Construction Schedule 2/4

ID	Text1	Task Name	Duration
83	2.22	MS-5-Diversion Tunnels 1 & 2 -Plugs+Grouting	181 da
84	2.23	KD2-8-Diversion Tunnels 1&2 -Plugs+Grouting-completed	0 days
85	2.24	U/S Cofferdam - Dam -El.357.00	180 da
86	**2.35**	**Main Dam**	**1989 days**
87	2.35.1	Main dam Excavation	400 days
88	2.35.2	Main Dam -Stage 1-El.450.00	1007 days
89	2.35.3	MS2-4-Main Dam-Stage 1-El.450.00 completed	0 days
90	2.35.4	Main Dam- Stage 2-El.473.00	181 days
91	2.35.5	MS2-5-Main Dam-Stage 2-El.473 completed	0 days
92	2.35.6	MainDam+Stage3-El.502.00	214 days
93	2.35.7	KD2-9-MainDam-Stage3-El.502-completed	0 days
94	2.35.8	MS2-16-LLO-El.340 = Closed & Plugged	0 days
95	2.35.9	Main Dam-Stage4	187 days
96	2.35.10	MS2-7-Main Dam Stage4-El.542.00	0 days
97	**2.37**	**Impounding**	**637 da**
98	2.37.1	KD2-9-Impounding Res.- Stage 1-El.355.00	181 days
99	2.37.2	KD2-10-Impounding Res.- Stage 2-El.467.00	91 days
100	2.37.3	KD2-11-Impounding Res.-Stage 3-El.496.00	180 days
101	2.37.4	KD2-12-Impounding Res.-Stage 4-El.520.00	55 days
102	**3**	**Lot-3 - Power Plant & Waterways**	**3233 days**
103		**Lot - 3 - Preparatory Works**	**832 da**
110	**3.7**	**Lot 3 - Contract Award**	**60 day**
112	3.9	Mobilization	370 days
113	3.10	MS2-2-Platform PH-El.345.00-Excavation-Zone Power House-Completed	0 days
114	**3.11**	**Power Plant**	**1971 days**
115		**Power House - Civil Works**	**1206 d**

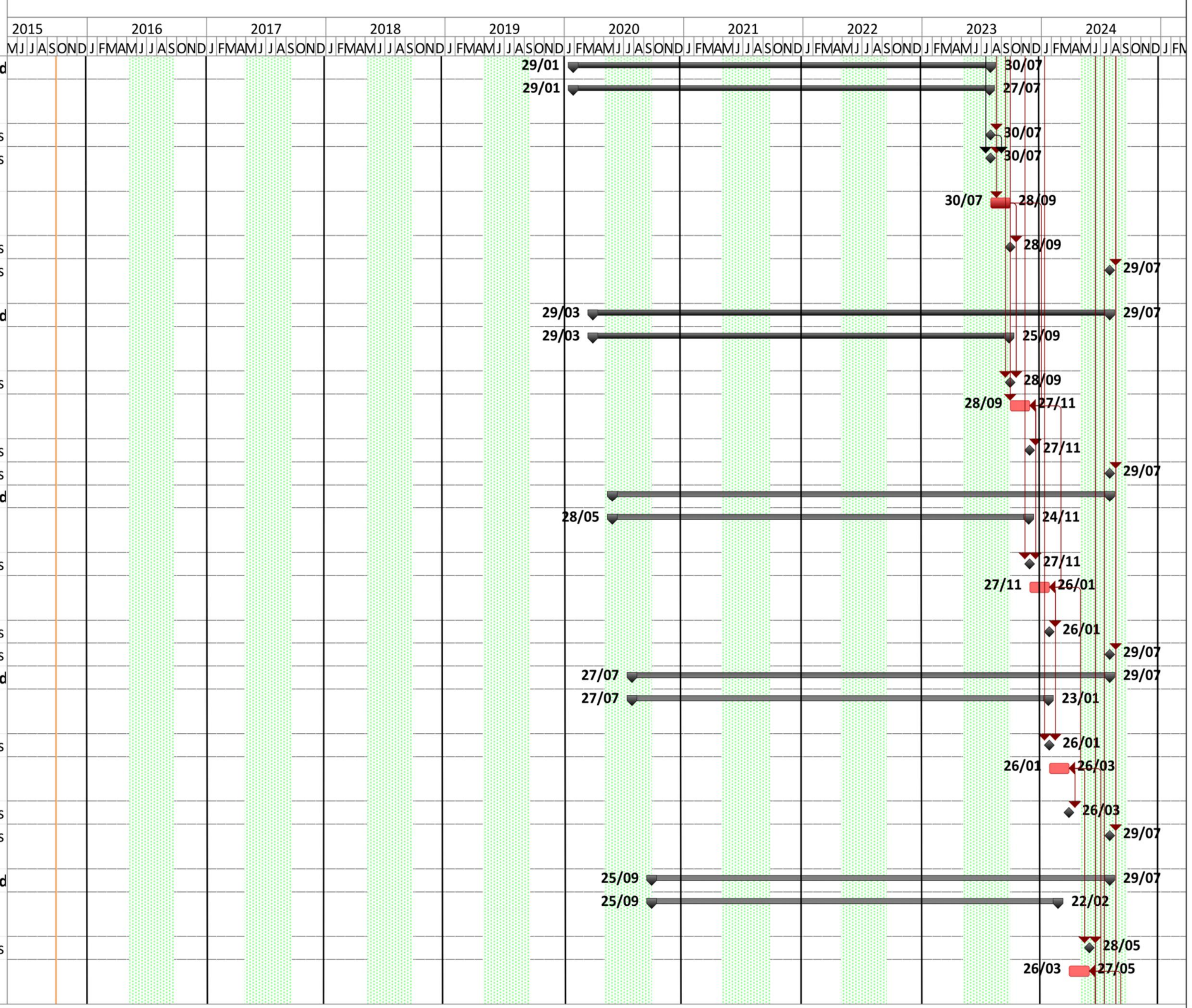


Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline					
Split	External Tasks	Inactive Summary	Manual Summary	Critical					
Milestone	External Milestone	Manual Task	Start-only	Critical Split					
Summary	Inactive Task	Duration-only	Finish-only	Progress					

Page 2

Figure 11-3 - Summary of construction schedule 3/4

ID	Text1	Task Name	Duration
127		**Unit 1**	**1278 d**
128		**Unit 1-Design-Fabric-Transport+Unit 1 HEM - Erection+Dry Tests**	**1275 days**
131	3.11.14	KD2-10-Impounding Res.- Stage 2-El.467.00	0 days
132	3.11.15	MS3-1-Unit 1-Wet Tests at El.467.00-start	0 days
133	3.11.16	Unit 1-Wet Tests at El.467.00	60 days
134	3.11.17	KD3-3-Unit 1-Commissioning at El.467.00	0 days
135	3.11.18	Unit 1-Comissioning at El.520.00	0 days
136		**Unit 2**	**1583 d**
137		**Unit 1-Design-Fabric-Transport+Unit 1 HEM - Erection+Dry Tests**	**1275 days**
140	3.11.21	KD3-4-Unit 2-Wet Tests at El.467.00-start	0 days
141	3.11.22	Unit 2 -Wet Tests at El.467.00	60 days
142	3.11.23	KD3-5-Unit 2 - Commissioning at El.467.00	0 days
143	3.11.24	Unit 2-Commissioning at El.520.00	0 days
144		**Unit 3**	**1523 d**
145		**Unit 3-Design-Fabric-Transport+Unit 1 HEM - Erection+Dry Tests**	**1275 days**
148	3.11.27	KD3-6-Unit 3-Wet Tests at El.467.00-start	0 days
149	3.11.28	Unit 3 - Wet Tests at El.467.00	60 days
150	3.11.29	KD3-7-Unit 3 - Commissioning at El.467.00	0 days
151	3.11.30	Unit 3 - Commissioning at El.520.00	0 days
152		**Unit 4**	**1463 d**
153		**Unit 4-Design-Fabric-Transport+Unit 1 HEM - Erection+Dry Tests**	**1275 days**
156	3.11.33	KD3-8-Unit 4-Wet Tests at El.467.00-start	0 days
157	3.11.34	Unit 4 - Wet Tests at El.467.00	60 days
158	3.11.35	KD3-9-Unit 4 - COMISSIONING at El.467.00	0 days
159	3.11.36	Unit 4 - COMISSIONING at El.520.00	0 days
160		**Unit 4**	**1403 d**
161		**Unit 4-Design-Fabric-Transport+Unit 1 HEM - Erection+Dry Tests**	**1245 days**
164	3.11.39	KD3-10-Unit 5-Wet Tests at El.467.00-start	0 days
165	3.11.40	Unit 5 - Wet Tests at El.496.00	62 days

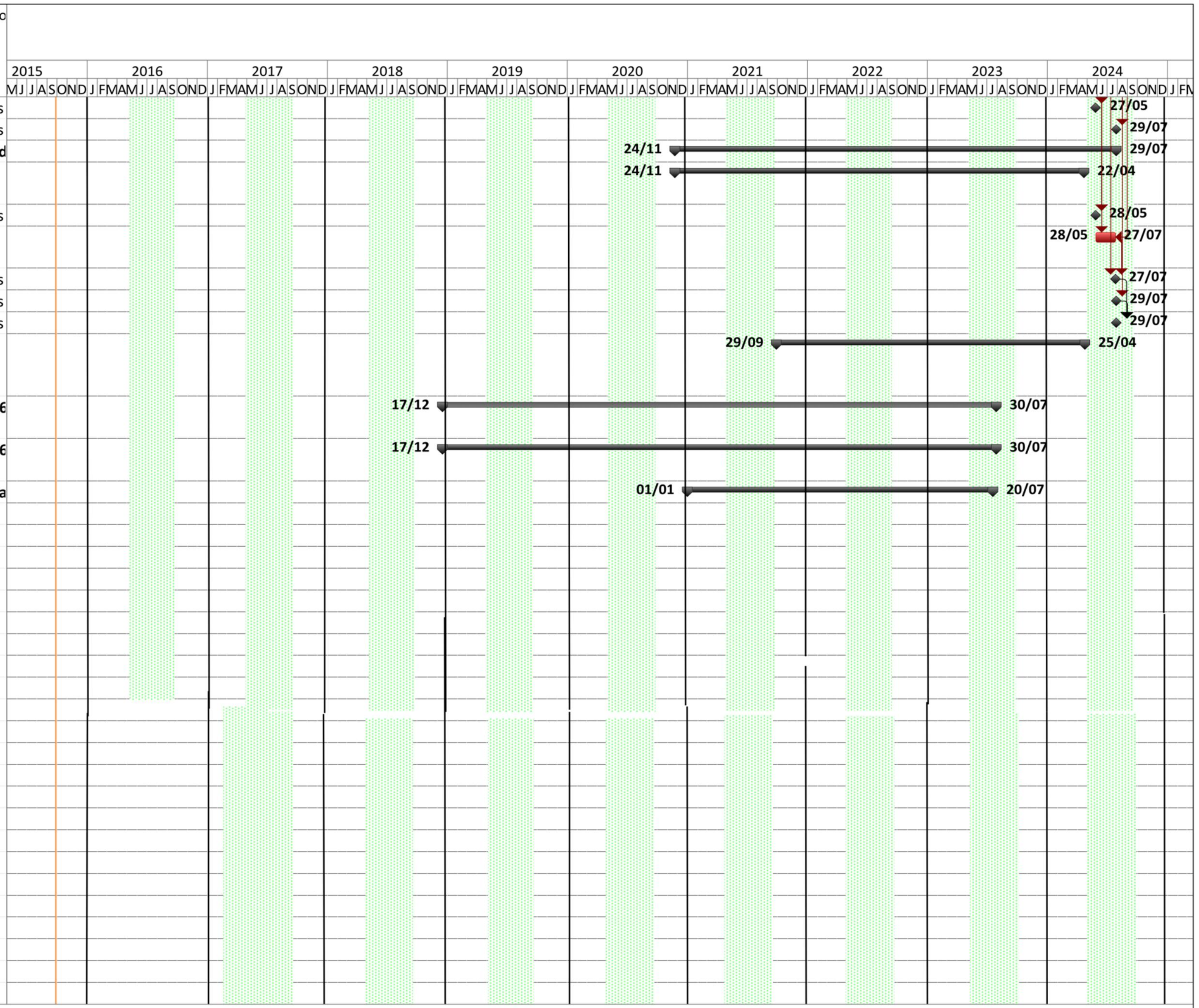


- Task
- Split
- Milestone
- Summary
- Project Summary
- External Tasks
- External Milestone
- Inactive Task
- Inactive Milestone
- Inactive Summary
- Manual Task
- Duration-only
- Manual Summary Rollup
- Manual Summary
- Start-only
- Finish-only
- Deadline
- Critical
- Critical Split
- Progress

Page 3

Figure 11-4 - Summary of construction schedule 4/4

ID	Text1	Task Name	Duration
166	3.11.41	KD3-11-Unit 5 - COMISSIONING at El.467.00	0 days
167	3.11.42	Unit 5 - COMISSIONING at El.520.00	0 days
168		**Unit 5**	**1343 d**
169		**Unit 4-Design-Fabric-Transport+Unit 1 HEM - Erection+Dry Tests**	**1245 days**
172	3.11.45	KD3-12-Unit 6-Wet Tests at El.467.00-start	0 days
173	3.11.46	Unit 6 - Wet Tests at El.467	60 days
174	3.11.47	KD3-13-Unit 6 - COMMISSIONING at El.467.00	0 days
175	3.11.48	Unit 6 - COMMISSIONING at El.520.00	0 days
176	3.11.49	MS3-2-All Units Commissioned at El.520.00	0 days
177		**Power House Overhead Travelling Crane + BOP-LV AC-DC system equipment for all Units completed**	**939 days**
186	**3.12**	**Power Intake**	**1685.6 days**
192	**3.13**	**Headrace Tunnels & Shafts & Penstocks**	**1685.6 days**
198	**3.14**	**Transmission Line & Sub Station completed**	**930 da**



Task | Split | Milestone | Summary
Project Summary | External Tasks | External Milestone | Inactive Task
Inactive Milestone | Inactive Summary | Manual Task | Duration-only
Manual Summary Rollup | Manual Summary | Start-only | Finish-only
Deadline | Critical | Critical Split | Progress

Page 4

11.2. Manpower requirement

The Budhi Gandaki HPP being a major project at the scale of Nepal, the manpower requirement has been estimated based on the most recent international experience of completed projects similar in size as illustrated the table below:

Project	Manpower		
	National	Foreign	Total
Tocoma 2160 MW Venezuela (2015)	?	?	3 000 to 6 000
Karahnjukar 690 MW Iceland (2007)	300	1 185	1 485
Gibe III 1870 MW Ethiopia (2015)	6 517 (Aug. 2014) to 3 666 (Nov.2015)	233 (Aug. 2014) to 138 (Nov.2015)	6 750 (Aug. 2014) to 3 804 (Nov.2015)
Budhi Gandaki 1200MW Nepal (peak requirement estimate)	**5 700**	**300**	**6 000**

Comments:

The Karahnjukar Project in Iceland is a very specific case. With a total country population of 311 000 habitants only in 2007, the Contractors employed directly about 300 Icelanders only. The rest of the manpower was hired from abroad with a large majority from China.

For Budhi Gandaki HPP the manpower can be estimated close to the manpower requirement of Gibe III HPP in Ethiopia because of i) the magnitude of the project, ii) the roller compacted concrete dam type of similar volume to the Budhi Gandaki HPP, iii) the similar national development context (GDP/capita)

Regarding the skill level one can estimate that out of the 5 700 national manpower requirement about 10 % (570) would be skilled , 20% semi-skilled (1 140) and 70% (3 990) unskilled.

12. PROJECT CAPITAL COST

When considering the composition of the bill of quantities and unit prices, it is usual for large hydropower plants to find that a very high proportion of the total basic cost of the civil engineering work and E&M equipment are covered by a r elatively small number of unit prices. It is acceptable to concentrate the analysis of unit prices on those major items with most influence on the total cost.

For Budhi Gandaki detailed study, the unit prices have been worked out from a data base developed by Tractebel Engineering, the so called aggregate price, that involves more than 50 projects around the world and from current under construction and planned projects in Nepal.

The project capital cost has been estimated to 2 593 MUSD

The Table 12-1 below presents the breakdown, of the Capital Cost

	TOTAL (USD)	2 592 750 744
Lot 1	Preparatory works	55 480 844
	Permanent roads	8 706 431
	Bridge	1 953 500
	Camp and facilities	44 820 913
Lot 2	Dam and appurtenant structures	1 026 077 849
	Thick Double Curvature Arch Dam	716 703 453
	Grouting	21 979 271
	Platform left bank between 542.00 - 610.00	47 238 140
	Bank galleries	10 247 366
	Monitoring	6 345 292
	Reservoir (support, leakage, etc.)	17 004 411
	River diversion	36 132 470
	Cofferdams	3 120 642
	Seismic Belt	22 885 487
	Gates + cranes	86 782 037
	Plunge pool and tailwater dam	29 773 176
	Platform left bank between 542.00 - 610.00	27 866 103
Lot 3	Powerhouse and waterways	548 748 725
3.1	Sub-system waterways	258 627 522
	Intake + gate shafts	22 765 898
	Headrace Tunnels (concrete lined)	8 327 677
	Headrace Tunnels (steel lined)	8 935 237
	Pressure shafts	25 380 569
	Steel lined tunnel from PS to turbine	62 821 973
	Gate shafts HSS	4 671 931
	Butterfly valve	27 558 780
	Turbine + Runner + Spiral case	60 977 365
	All Draft Tube	8 203 733
	Tailrace channel	17 603 174
	Tailrace - stoplogs	4 840 326
	Adit tunnel	6 540 860
3.2	Sub-system electricity	188 525 284
3.3	Sub-system auxiliary services	54 959 954
3.4	Sub-system Civil work powerhouse	46 635 965
	Powerhouse	45 937 612
	Talweg protection	698 353
4	Environmental costs	612 042 703
5	Contingencies	350 400 623
	5% unmeasured items	79 970 371
	10% contingencies for civil	106 956 494
	10% contingencies for HEM	43 651 941
	8% contingencies for Transmission Line	2 472 000
	Transport, erection/site tests/commissioning, spare parts 2y, Warranty 1y = 18% HEM	60 289 057
	Engineering admin (3.5% civil HEM)	57 060 760

Table 12-1: Breakdown of Capital Cost

The Figure 12-1 and Figure 12-2 below shows the di stribution of the by l ots and by speciality. It can be observed that the lot 2 is nearly 50% of the cost estimate and the civil works represent more than 50% of it.

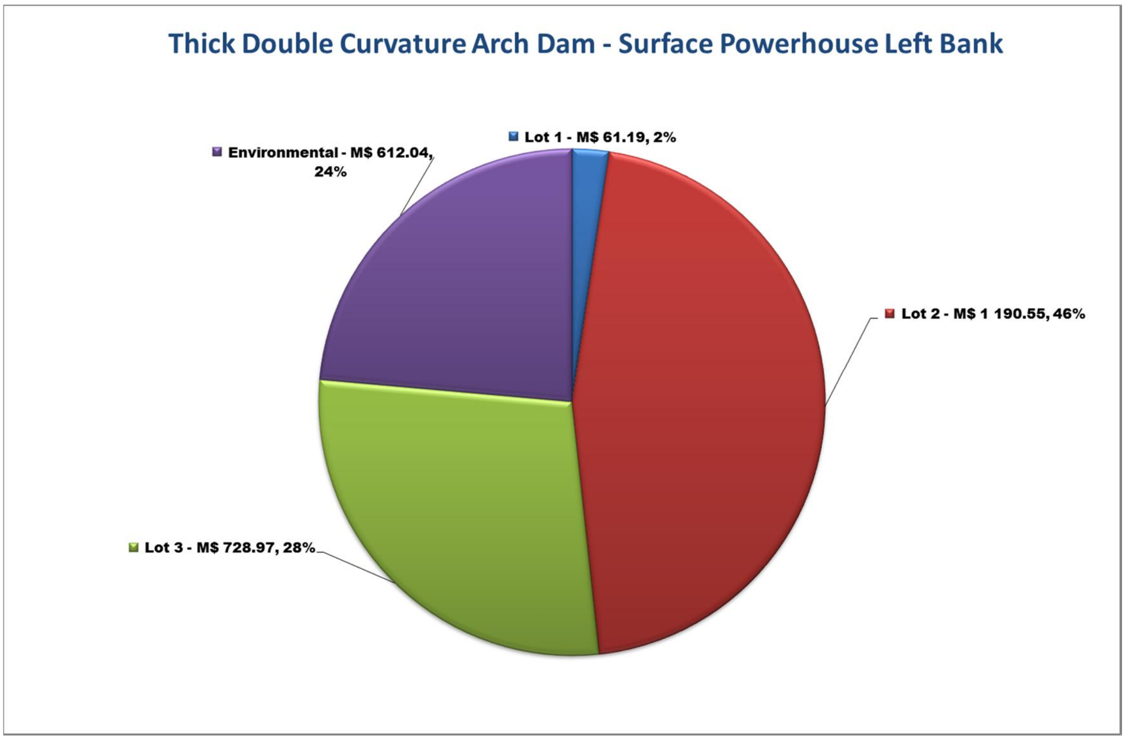


Figure 12-1: Total cost of the project – Lots' weightage

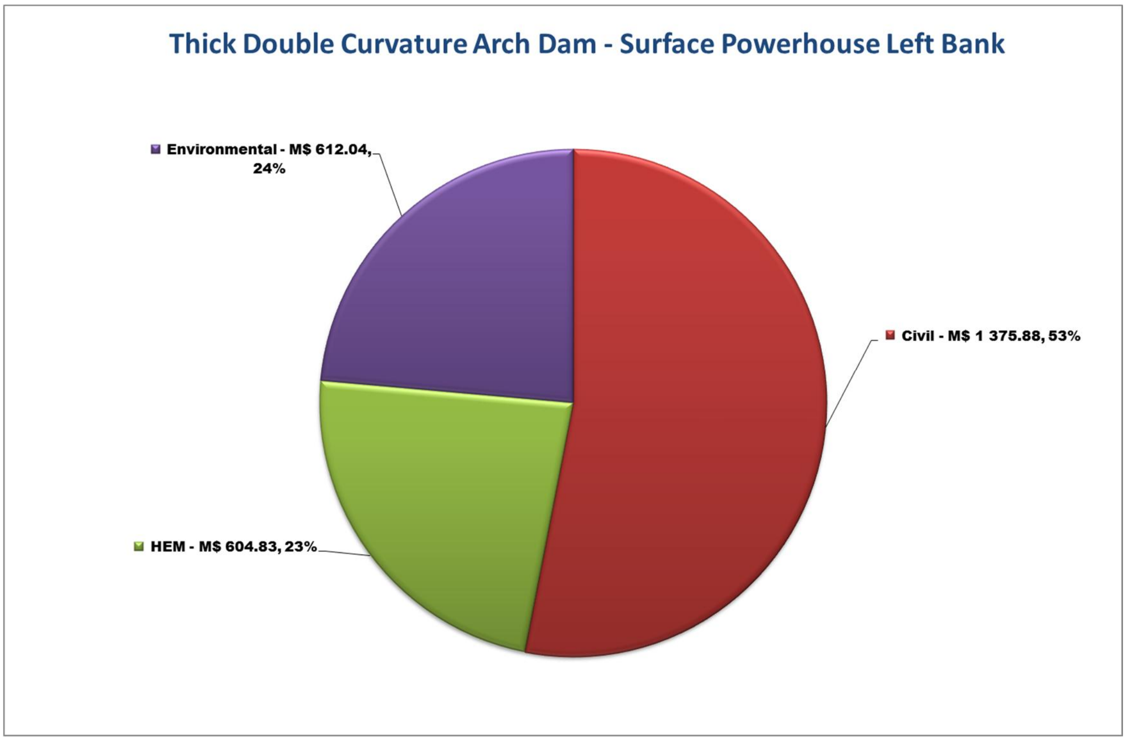


Figure 12-2: Total cost of the project – Civil, HEM and Environmental Cost weightage

Breakdown of Unit Prices

The breakdown of unit prices presents the cost estimate from à contractor's point of view for the civil work only. It follows the resource based costing and recognized standard measurement methods as per international standard practice and Nepalese practices. Only the prices representative of the Lot 2 & 3 have been detailed, these 14 prices cover 90% of the civil work of this lots. This breakdown of Unit Prices is presented in the Volume 15 Appendix A-1 Ref BG-DDR-Vol15-A1.

Costs comparison with other projects

The following Figure 12-3 and Figure 12-4 present the points [capital costs vs installed capacity] for the Budhi Gandaki Project. Access roads, Transmission lines and Environmental costs are excluded.

The points corresponding to [capital costs vs installed capacity] of recent Hydroelectric Projects (constructed or under construction) in which Tractebel Engineering is or has been involved are also plotted.

One can observe that the Budhi Gandaki Project [capital costs vs installed capacity] lies within the group of points but above the average trend. This can be explained by the fact that the Budhi Gandaki Project does not benefit from a natural head, the same being essentially created by the dam which has a major weightage in the total capital cost as illustrated above.

FSL	**masl**	**540**
Q	**m3/s**	**671**
Capacity	**MW**	**1 200**
Head	**m**	**260**
	MW / H^0.3	226
Total cost	MUSD	2 592
Environ. & Social cost	MUSD	612
Road bridge	MUSD	10.7
Trans Line	MUSD	33.4
TOTAL Cost **(Generation component only)**	**MUSD**	**1 935.9**
	USD/MW	**1.61**

Table 12-2: Budhi Gandaki –Project Cost and parameters

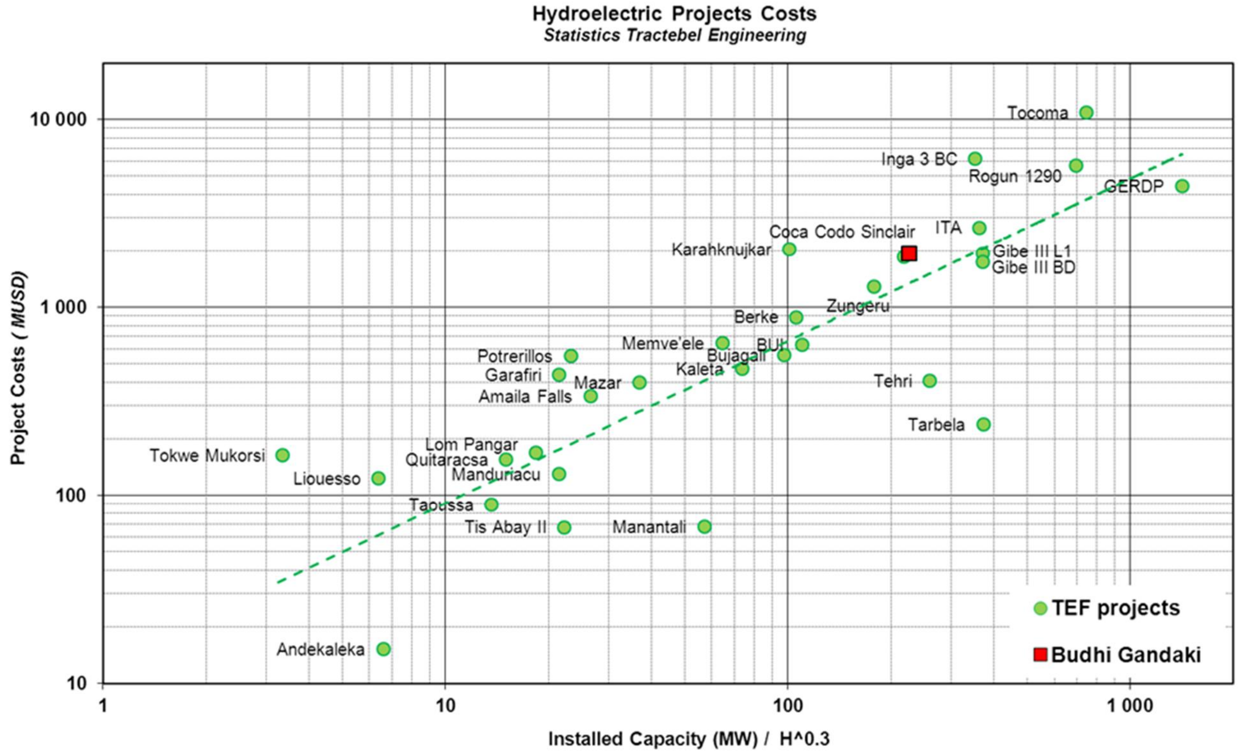


Figure 12-3: Cost comparison: Project cost VS Installed Capacity / $H^{0.3}$

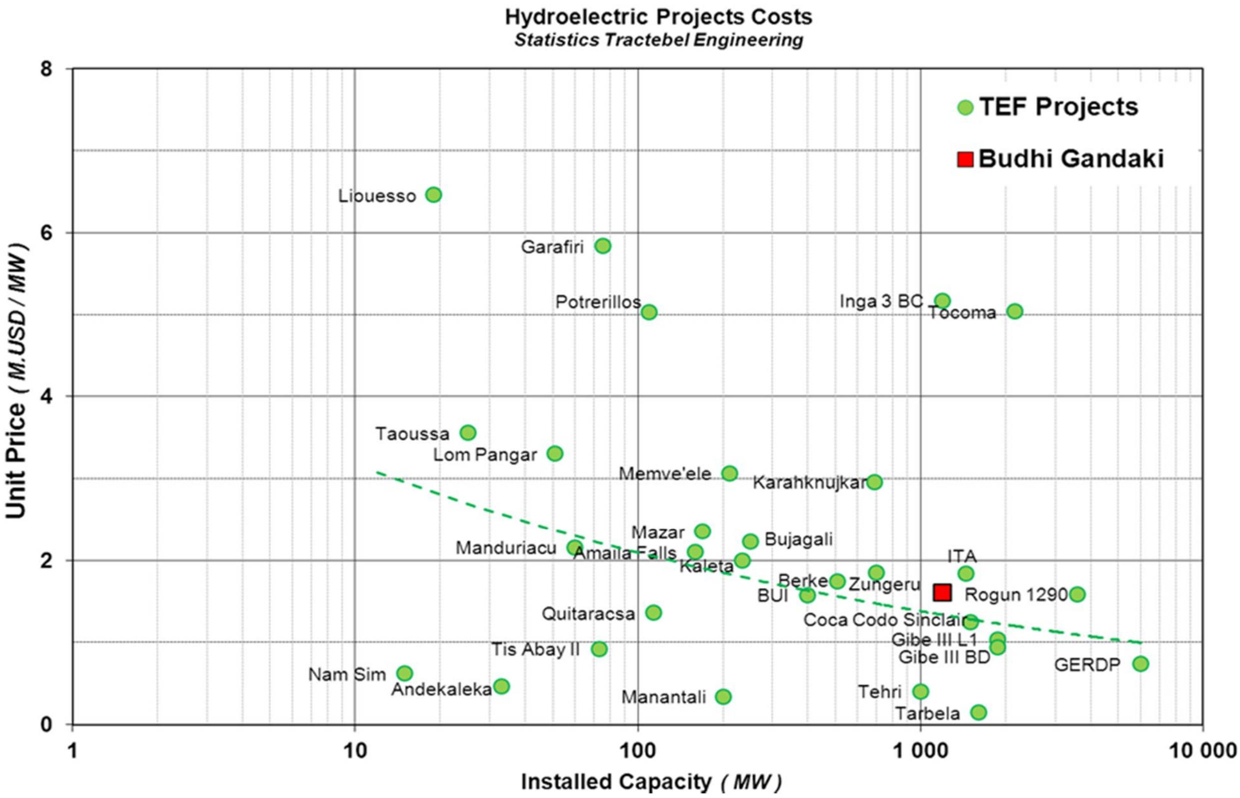


Figure 12-4: Cost comparison: Unit Price VS Installed Capacity

13. ECONOMIC AND FINANCIAL ANALYSIS

In order to assess the financial and economic viability of Budhi Gandaki it is necessary to determine the attributable benefits resulting from the commissioning of the plant, which in turn relate to the energy absorbed by the NEA system as well as possible energy exchanges with India. It is noted that such exchanges, initially in the form of exports, could be reversed with time due to the anticipated high growth in electricity demand within Nepal.

Two power generation scenarios, as presented in sections 4.2 and 4.4 above, have been considered in the economic and financial analysis. They are corresponding to a conservative approach of the river runoff at project site as presented in the Feasibility Study Report and to a revised river runoff estimate based on latest river discharge measurements and presented in the Detailed Design Report :

Table 13-1: Generation Scenarios

Generation Scenario	Mean Annual Energy GWh/year	Winter season or Dry season Energy GWh	Wet Season Energy GWh
N°1	3 383	1 408	1 975
N°2	4 250	1 623	2 627

In order to assess the viability of the Budhi Gandaki project, the operation of the power system in Nepal was simulated every year on a seasonal basis over the period up to the time when it was estimated that the output of the plant is fully assimilated within Nepal. The results of this simulation, for the base case demand forecast and Generation Scenario N°1, are tabulated below.

Table 13-2: Energy generation planning in Nepal

Year	Season	Total demand (Medium scenario)	Hydroplants and other renewables	HFP plants	Budhi Gandaki	Energy imports	Projects to be developed (or load shedding)
2022	Wet	5993	5993	0	0	0	0
	Dry	4280	1855	200	0	657	1568
2023	Wet	6498	6498	0	0	0	0
	Dry	4642	1855	200	0	657	1929
2024	Wet	7091	7091	0	0	0	0
	Dry	5065	1855	200	0	657	2352
2025	Wet	7667	7667	0	0	0	0
	Dry	5476	1855	200	1408	657	1356
2026	Wet	8248	8248	0	0	0	0
	Dry	5891	1855	200	1408	657	1771
2027	Wet	8805	8805	0	0	0	0
	Dry	6289	1855	200	1408	657	2169
2028	Wet	9462	9197	0	266	0	0

Year	Season	Total demand (Medium scenario)	Hydroplants and other renewables	HFP plants	Budhi Gandaki	Energy imports	Projects to be developed (or load shedding)
	Dry	6759	1855	200	1408	657	2638
2029	Wet	10085	9197	0	888	0	0
	Dry	7203	1855	200	1408	657	3083
2030	Wet	10825	9197	0	1629	0	0
	Dry	7732	1855	200	1408	657	3612
2031	Wet	11511	9197	200	1975	139	0

The Table 13-2 above illustrates the critical role played by Budhi Gandaki in ensuring that the prejudicial load shedding in the dry season is reduced. During the wet season, most of the project's energy will be sent to India in the first years of operations (2024 and 2025). As demand grows in Nepal this is eroded to a level of 10% by 2030.

The economic value of the project is assessed based on the merits of dry s eason generation, with the value of t he project's dry energy valued at the cost of dry energy generation from run of river projects. This value was determined to be 425 $/MWh for dry energy and 0 $/MWh for wet energy. For reservoir projects, this is equivalent to a value of 179 $/MWh for the annual energy; while it i s equivalent to 64 $/MWh for Run of River projects. This method allows giving a value to the reservoir, which is the main benefit driver for the Nepalese network.

Under the most conservative generation scenario, the **project's economic internal rate of return is of 15,5%** (expressed in nominal terms). In this r egard, and under the most conservative assumptions, the project appears economically attractive.

In addition to dry energy generation to which an economic value was attached, there will be additional benefits which were not quantified as follows, and which will increase the effective EIRR:

- Positive downstream impact on existing and planned generation assets
- Irrigation leading to increased agricultural yields; and
- Improved flood control.

Following the commissioning of Budhi Gandaki, it is anticipated that it will not be poss ible to absorb a significant proportion of total energy generation within Nepal. Should it be possible to conclude an agreement with India whereby energy is effectively "banked" over a period of years, with repayment of energy in the future allowing savings in the costs of developing additional generating plant, the EIRR for the project is be expected to rise. It is understood that the concept of energy banking has now been adopted within India. The signature and ratification of a Power Trading Agreement between the Governments of Nepal and India, and the planned creation of a regional grid creates a broader opportunity for such innovative trading arrangements with other countries.

The low Financial Internal Rate of Return (FIRR) - 7% in the most conservative case, and 8,6% in the second generation scenario - illustrates the impact of the relatively low level of tariffs currently charged in Nepal.

A financial sustainability analysis was performed. It was found that the project would be financially sustainable under concessional loan arrangements. However, due to its long construction period and high costs, and taking into account the significantly lower maturities of commercial debts available for projects in Nepal, revenues generated by the project will not be sufficient to cover its operating costs and debt service payments. Under such a scenario, a significant contribution from the project's shareholders would be needed.

An analysis was also undertaken into the tariff which would be sought by an IPP developer of the project. Under a scenario with typical developer return of equity values of 20% and adapted commercial debt strategy, the equivalent cost per unit energy supplies would be of 21,5 US cents per kWh for the conservative generation scenario (and 17,5 US cents per kWh for the second generation scenario). These values are three to four times higher than the revenues which NEA would receive from Nepalese customers (after deducing losses and transmission and distribution charges) or from exports to India, and would therefore potentially prejudice the financial stability of the company. The extent to which any commercial lender would accept such an arrangement is also questionable.

Under an alternative scenario, with the assumption of very soft concessional financing and a longer PPA term, lower equivalent energy costs are observed (14,5 $cts/ kWh and 11,5 $cts/kWh). If the equity were to be shared between parties in Nepal who are prepared to accept lower returns on equity, and international developers, bringing the overall return on equity requirement to 10%, the unit energy price would be 7 $cts/kWh in the most optimistic scenario, which is closer to the unit revenue generated by NEA from its customer base.

14. FINANCING AND CONTRACT SETUP FOR THE PROJECT IMPLEMENTATION

14.1. Context

The Budhi Gandaki HPP is a s torage project which has the specific aim of providing electricity during the dry season. These two main features make the project both very valuable for the country and costly. The project is highly valuable for the country economical and politically because it would contribute to the independence of Nepal in term of energy and it w ould develop the economy and the welfare of the Nepali citizens. As detailed in previous Section 12, the BG HPP represents also a huge investment due to its features of storage and of peak energy production.

Such features would impact on the financing choices.

14.2. Financing arrangement alternatives

Several financing arrangement could be considered:

- **Public Ownership Development:**
  - *Financing by Multilateral Institutions* –International Competitive Bidding’s procurement under rules of the IFIs with either Employer’s or Contractor’s Design. This is a very long and complicated process which can take years to be implemented (even with partial financing) and not in line with the time line requirement expressed by the Government of Nepal.
  - *Full Self-Financing* (Finance as-you-Go) – 100% GoN: ICB under rules selected by the Owner with either Employer's or Contractor's Design. High Yearly Cash is needed (up to 650 mUSD/year) rendering this solution not practicable since these cash need represent some 5% of the GDP.
  - *Partial Self-Financing and Supplier's Credit* under Loan made by a Commercial Bank insured/improved by an Export Credit Agency for E&M Equipment. In that case, two EPC Contracts could be proposed with a Main EPC Contractor and a Plant Contractor. The rights and obligations of the Owner under the Plant Contract may, then, be assigned to the Main Contractor (example of the 1,870 MW Gibe III HPP in Ethiopia) or the Plant Contractor could be a Nominated Subcontractor to the Main Contractor. Equipment represents only 25% of the total costs of the project. Under such a development scenario, the yearly cash needed would be slightly reduced rendering this solution more feasible.
  - *Preferential Buyer’s Credit Loan Agreement for the Complete Project* and insured by an Export Credit Agency: 15 to 25% of the Total Investment Cost would be brought by the GoN and 85 to 75% would come from the Loan. One EPC Contract with a Contractor sourced in the Country awarding the loan (Examples of the 700 MW Zungeru HPP in Nigeria, 400 MW Bui HPP in Ghana, 1,500 MW Coca Codo Sinclair in Ecuador, 250 MW Memve’Ele HPP in Cameroun, etc).

- *Partial Self-Financing, Bonds on National Market, Eurobonds and Supplier's Credit* under Loan made by a Commercial Bank insured by an Export Credit Agency for E&M Equipment – (example of the 6,000 MW Grand Ethiopian Renaissance HPP in Ethiopia) – Good if Bonds can be raised on the local market

- **Full Private Ownership Development.**

  In that case, financing of the Equity would be brought by Private Sponsors (20% minimum), the Loans would come from DFIs (Private Counters of Multilateral Institutions (50 to 60%) and from Commercial Banks guaranteed by PRG of WB or Exim Banks (20 to 30%): ICB's Procurement under rules of the IFIs with either Employer's (under measured quantities) or Contractor's Design (EPC type Contracts) – Example of the 250 MW Bujagali Project in Uganda or 700 MW Birecik Project in Turkey – It is also a very long and complicated process – Loan conditions are not concessional rendering the feasibility of this approach very uncertain (required RoE by Private Sponsors difficult to achieve)

- **Full Private/PPP Ownership Development:**

  In that case the financing of the Equity would be brought by Public and Private Sponsors (20% minimum), including Concessional Loans from Multilateral Institutions to finance the Public Investment Company (of Nepal),

  A Preferential Buyer's Credit Loan Agreement would be used for the rest of the Financing insured by an Export Credit Agency and with concessional conditions (20 years maturity, 2 to 2.5% interest rates and 5 years grace period) – (80% of the Total Investment Cost)

  This type of credit may require only one EPC Contract with a Group of Contractor/Suppliers sourced in the Country awarding the loan. This may be a good solution in particular if the Indian soft loan (part of the credit line opened by India on 2014) can be used for the Project.

From the above, it can be concluded that **the Financing arrangement should maximize the soft concessional loans** to ensure reasonable Return on equity (RoE) to Equity Investors (different for Public/Private).

The general consequences are the following:

1) Public Ownership with Financing from Multilaterals will be long and difficult
2) Public Ownership with Full Self Financing requires high yearly cash needs and appears also very difficult
3) **Public Ownership with Partial Self Financing and Supplier's Credit** for the Equipment under soft loan conditions is **better and can be improved by raising Bonds**
4) **Public Ownership with Preferential Buyer's Credit with soft loan conditions** (non OECD Countries) can be seriously envisaged and **is the preferred option**
5) Private Ownership with Equity, DFIs and Commercial loans will be also very difficult because not ensuring the expected RoE

6) Public-Private Partnership with Equity and Preferential Buyer's Credit under soft loan from non-OECD Countries (India-China) is highly feasible but very likely more time consuming than option 4

The two preferred options are the ones indicated here above in points 3 and 4:

Specific context of the Budhi Gandaki HPP

The Economic and Financial analyses updated in the Detailed Design Report and presented in the Volume 16 (Ref BG-DDRVol16-FINAL) is showing:

- a Financial Internal Rate of Return **(FIRR) of 7% under the first generation scenario and 8.6% for the second generation scenario** (both expressed in nominal terms) assuming current energy prices in the country and for export to India (wet season energy) and a long term inflation assumption of 2%.
- that if considered as an IPP, the necessary energy prices should be higher than 17 Cents USD/kWh under classical assumptions of expected Return on Equity (RoE) of around 20% for the Investor and conventional commercial loans for the long term Debt.
- These prices go down to **9 cents USD/kWh and even 7 cents USD/kWh under the assumption of a long term Debt constituted by a Soft Concessional loan** and a RoE of 10%. It has to be noted here that these prices are close to the currently observed prices in Nepal and for exports to India

This is showing that the Project may be developed and implemented **only if a significant portion of the Total Investment Cost (TIC or CAPEX) is constituted by a Soft Concessional loan having long maturity period (20 years), long grace period (6 to 7 years) and low interest rates (less than 2 to 3% per year).** This excludes the recourse to Private Investment or to Public Private Partnership and is calling for a Public Ownership in a way similar to the one used for the implementation of the 456 MW Upper Tamakoshi Hydropower Project under construction.

Recommended Financing options

These Soft Concessional loans may be awarded as a Supplier's Credit for the financing of the E&M Supplier's Contract (30 to 40% of the Power Component cost of the Project) or as a Buyer's Credit for the complete project (75 to 85% of the Power Component cost of the Project). **The possibility to obtain such a loan is high and should be explored as soon as possible. The possible use of the soft credit line awarded by India under a bilateral cooperation agreement between India and Nepal should be explored as soon as possible in this respect.**.

Assuming that a Soft Concessional loan is obtained, the rest of the financing of the TIC can be arranged as Equity by the GoN (State budget) and investment of state owned Companies and debt by raising Bonds on the local financial market. The importance of the Equity and of the debt will depend on the portion of the TIC not covered by the Soft Concessional loan. Here also, the possibilities to attract investment from state owned companies and to raise bonds should also be explored as soon as possible in order to elaborate better the financing scenarios and deepen the financial feasibility of the Project's implementation.

It has to be noted here that the award of the Soft Concessional loans will be done under the conditions that the equipment or the works to be financed by the loans be sourced in the country which is awarding the said loans and that the supplier's or the construction contract be of the turnkey type (or EPC type).

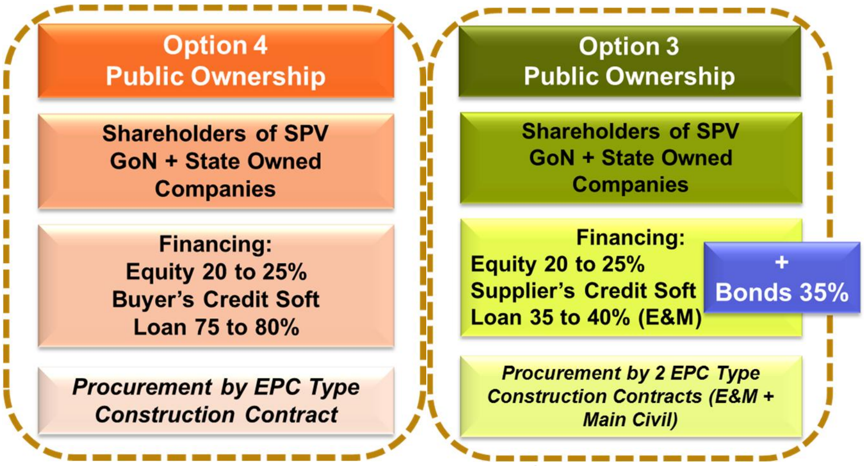


Table 14-1: Recommended Options

14.3. Contracts setup

The above presented financial arrangement implies to the division of the construction contract in 3 distinct lots. The physical limit between the lots considers the general layout and the performance responsibilities in view of limiting to the strict minimum the interferences between the Contractors:

- **Lot No. 1**: Preparatory Works (including the access roads, the bridge over the Budhi Gandaki river and the camps for the Employer and the Contractor),

- **Lot No. 2**: Dam and appurtenant works including the tailwater dam and the Diversion Tunnels,

- **Lot No. 3:** Complete Power component including power intake , headrace tunnels, power house civil works and HEM equipment, tailrace channel, switchyard GIS transmission line substations.

Construction Contracts for Lots Nos. 2 and 3 are recommended to be elaborated on the EPC (Engineering Procurement and Construction) type basis in order to satisfy with the possible requirements of the Lenders whereas the Construction Contract of Lot No. 1 can be based on payment as per quantities and unit rates with an Employer's design.

The EPC concept is appropriate to the projects which present a low degree of contingencies and a high knowledge of the geotechnical context. BG HPP presents a very compact design and few underground works which limit the contingency. In addition, extensive field investigation surveys have been conducted between 2013 and 2015 which provide a high degree of knowledge of the project area.

The Tender Documents for both Lots Nos. 2 and 3 should also include, besides the offer for the design and construction of the Project, **a request for providing the financing of the proposed amount for the considered Lot under Soft Concessional terms**

14.4. The proposed Fast Track approach

As BG HPP is a crucial project for the economy of the country, the time is a high constraint to take into account. A development and implementation schedule has been elaborated and proposed in the **Figure 14-1** below.

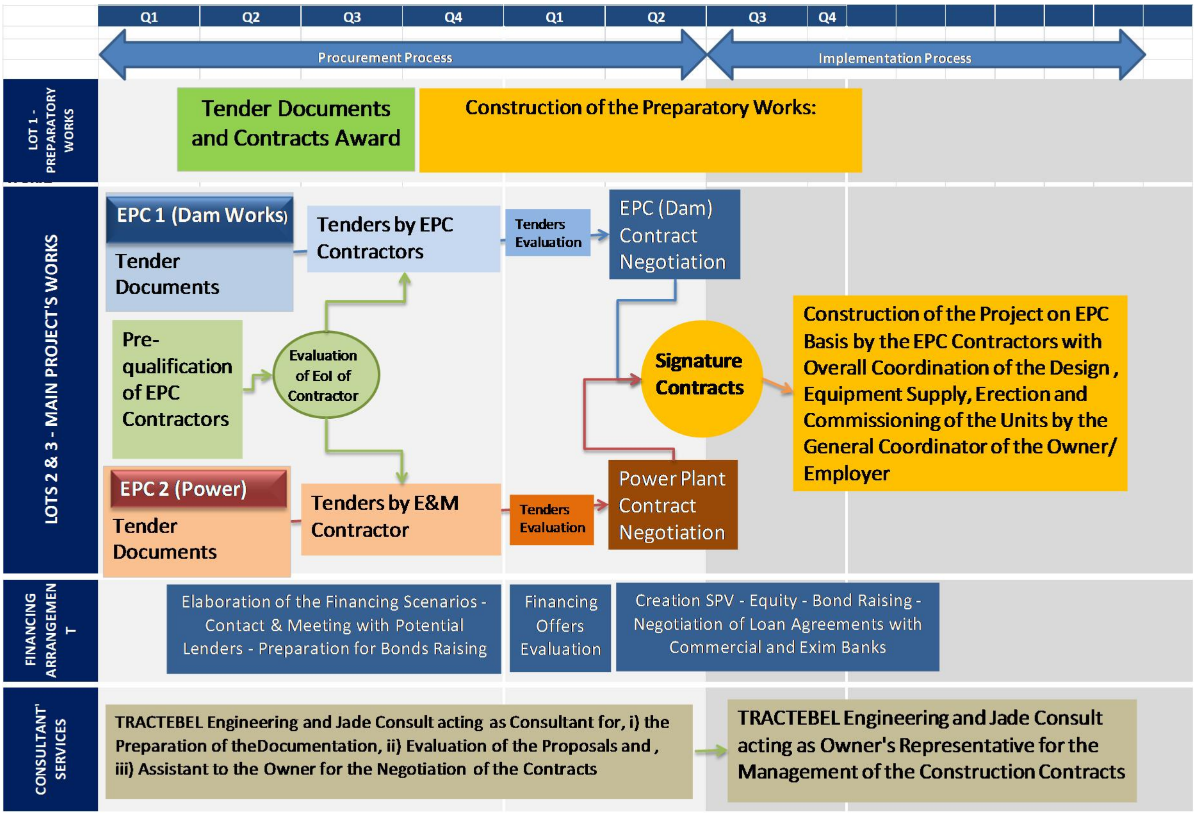


Figure 14-1: Fast track approach implementation schedule

14.5. The Special Purpose Vehicle

It could be envisaged that a Special Purpose Vehicle (SPV) could be set up by the Government of Nepal associating the NEA and several other Public Entities like in the case of Upper Tamakoshi. These associates should have a majority stake in this SPV (51% and more).

Other shareholders (public and private) could join the main associates. This SPV should be able to mobilize between 20 and 25% of the CAPEX (being the addition of the construction costs, the interests to be paid during the construction, the development costs, a Debt

Service Reserve amount, etc.) as the Equity. It is assumed that the Environmental mitigation costs would be supported directly by the Government.

The Owner shall establish a Project Management Unit (PMU) who shall be in charge of managing and administering the preparation, negotiation, award and then performance of all the contracts and agreements necessary for the successful commissioning and operation of the Project.

This PMU shall include several sub-units who will be dealing with several important subjects and issues like, i) the implementation of the Environmental Impacts Mitigation measures, ii) the construction of the Preparatory Works, iii) the construction of the power component of the Project, iv) the loan agreements (Financial Advisors), v) the legal and contractual issues (General Counsel), etc.

For their operation, the PMU and the sub-units may require the assistance of external engineering, legal and financial advisory firms.

At the time of commissioning and operation of the plant, the structure of the PMu shall evolve and incorporate specialized operators' personnel and, possibly at least at the start of the operation, an external engineering firm specialized in dam and power plant operation and maintenance.

On the basis of the above, the following organization chart is proposed:

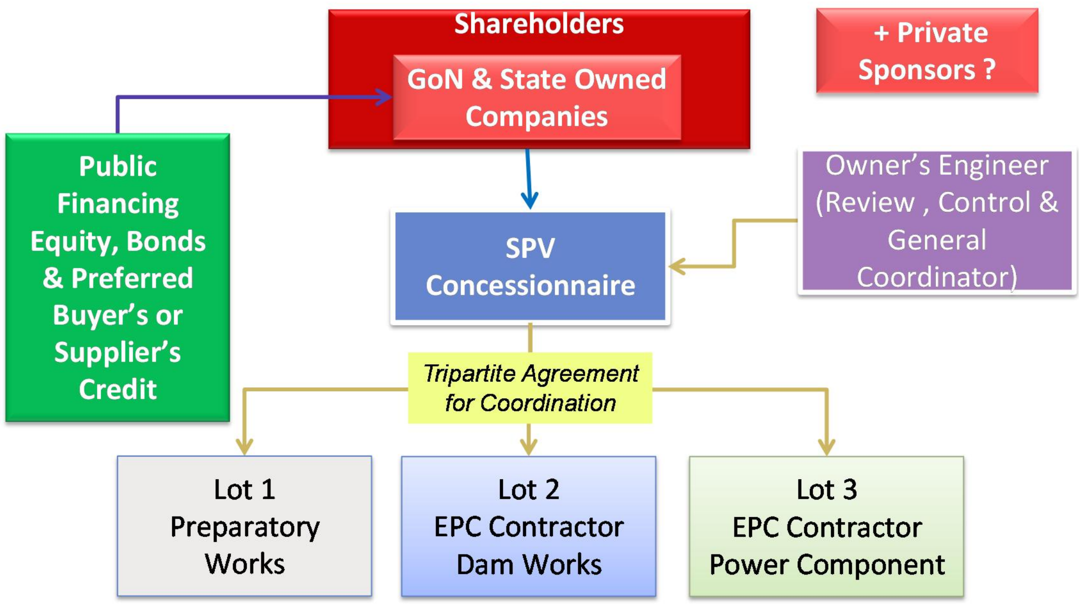


Table 14-2: Organization Chart

14.6. The Debt Portion of the CAPEX (Credits and Bonds' raising)

The debt portion of the CAPEX (say 75 to 80%) would come from various sources like a Preferential Buyer's Credit or Supplier's Credit which would be tied to the sourcing of the Construction Contractors and/or Suppliers and/or Bonds raised locally by specific Financial Institutions.

As shown before, to achieve an energy cost of around 7 to 9 Cents USD/kWh (levellized tariff), it is of utmost importance to obtain soft terms and conditions for the loans (long maturity period of at least 20 to 25 years, long grace period of at least 6 to 7 years and interest rates below 2.5% per annum).

The Government of Nepal should without delay explore these possibilities and a request of loan facilities has been introduced in the Tender Documents to this effect. Regarding the possibility to raise bonds on the local market, this should be explored also as soon as possible using the services of specialised financial advisors (either international and/or national). The Indian soft loan mentioned here above could be one of the required sources of credit.

It would be of course of utmost importance to support these loan investigations and possible bonds' raising that Power Purchase Agreements be elaborated and discussed by possible offtakers both in Nepal (dry season energy to be sold to the NEA) and, if possible, in India especially for the wet season energy in case there is a surplus during the first years which will follow the commissioning of the Project.

15. INSTITUTIONAL ARRANGEMENT FOR PROJECT IMPLEMENTATION

15.1. Needs

15.1.1. Needs for high level and strong Resources and Means

The Owner shall, in principle, have the proper resources and means to be capable to:

- Do the proper diligences to discuss, organize and, finally, set up with the highest authorities of the Country the planning for the procurement activities and, above all, in the arrangement of the financing for its implementation.
- Start and organize the procurement process including the selection of the Tenderers who will be invited to tender for the construction, answer to the questions raised by the tenderers, perform a comprehensive evaluation of the proposals submitted by the tenderers, discuss and finalize the contracts with the Contractors, etc.
- Fulfill all required obligations of the Employer under the contracts: i) designate the Employer's Representative ("the ER"), ii) award the proper mandate to this Representative to manage and administer the construction contracts in accordance with the mandate, iii) constitute teams in charge of performing the tasks outside the mandate of the Employer's Representative (payments to the Contractors, management of the guarantees, excepted risks, treatment of Variations and Claims with the assistance of the ER, the specific obligations of the Employer in relation to environment impacts, the site lands' ownership, etc. iv) constitute teams who will be counterparts of the Employer's Representative team members, etc.
- Set up within its organization a specific "environmental and social section" dedicated to the management of detail design of the environmental and resettlement action components, and to management of the implementation thereof.
- Prepare the grounds for the operation of the Project by deployment of specific personnel to the site for proper training at the time of the erection of the main E&M and Electrical Equipment, their Tests on Completion, the issuance of the Taking over Certificates, the performance of the Tests after Completion, the issuance of the Final Completion Certificates, etc.

15.1.2. Needs for experienced Teams and Experts

It is clear from the above that the carrying out of all these tasks and activities require large and very experienced teams and experts in the following fields:

- Large infrastructure financing arrangement involving Export-Import banks, export credit agencies, raising of bonds in the local financial markets, syndication of lending agencies, providing guarantees, etc.,
- Power Purchase Agreements with local and international authorities,
- Large infrastructure contracts general management including entertaining the relations with and proper reporting to the concerned Ministries and Administrations, loans and accounting management, etc.

- Technical management for the construction contracts including the control of the quality, the design performed by the Contractor, the quantities of the implemented works, the control of the certificates issued by the Contractors, etc.
- Administrative management in relation to the environmental and socio-economic impacts of the Project, the land ownership and need of compensation of the site area, etc.
- Hydropower projects operators with E&M, HSS and Electrical Equipment Experts, etc.

15.2. The Owner's Governance

15.2.1. The Budhi Gandaki Hydropower Project Development Board

A special Board named the Budhi Gandaki Hydropower Project Development Board ("the Board") has been formed by the Government of Nepal ("the GoN") in 2012 for the purpose of constructing the Project making power services reliable and available for all and extending of hydropower (Art. 3 (1) of the Government Executive Order). This Act was subsequently amended on December 15th 2014.

Such a Board shall consist of the following members:

- The Chairperson nominated by the GoN
- A Joint Secretary, Ministry of Energy - Member
- A Joint Secretary, Ministry of Finance - Member
- The Director General, Department of Electricity Development (DoED) - Member
- The Executive Director, Nepal Electricity Authority – Member
- Three Experts in the field of hydropower nominated by the GoN – Member
- Executive Director, BGHPDC – Member Secretary

A Secretary (at least Gazetted Second Class Officer) is nominated by the GoN.

The tenure of the Chairperson and of the other members shall be four years and they can be nominated again one time. Both the Chairperson and the Group of experts shall have specific experiences and qualifications in terms of hydropower design, planning, construction, environmental, law, management, etc.

15.2.2. Functions, Duties and Rights of the Board

The Board has, in principle, the following functions, duties and rights:

- To hold or cause to hold survey, study, research, evaluation and monitoring of the Project,
- To do or cause to be done the development work of the Project if the Project is financially and technically appropriate,
- To prepare the required policies, plans and programs for maintaining the active participation of the local people in the development process of the Project for the development and construction of the Project,
- To manage the work of the contract according to the need for the construction of the Project,

- To have services according to the need for construction, supervision, monitoring and management of the Project,
- To do or cause to be done the necessary work for rapid implementation of the Project,
- To approve the cost estimate for the Project
- To prepare the bidding documents for the purpose of calling bids on the basis of national and international competition for the implementation of the Project,
- To approve the bids according to the prevailing laws,
- To supervise the Project and provide necessary direction to solve the problem overseen during the supervision,
- To approve annual budget and programs and implement or cause to be implemented this,
- To do other works relating to the Project implementation and management according to the specification.

15.3. The Employer's Representative requirements

15.3.1. Introduction

The organization to be set up for the proper management of the Employer's activities and tasks is different for the Pre-Construction and the Construction Periods since in the Pre-Construction Period, the most important is to seek the financing, discuss the Power Purchase Agreements and conclude the procurement process for the construction whereas, during the Construction period, the most important is to manage both the construction contracts and implementation of the EAP and LARRAP, with the objective to meet with the requirements in terms of Time for Completion, Overall Fixed Price within original budgeted figure and of overall Performance.

15.3.2. The Pre-Construction Period

Due to the exceptional nature and size of the Project as recalled here above as well as its international orientations, it is advised that the Board, or any future nominated entity associates with several (3) high levels Consultants in the following fields:

- Financial Advisory Services to assist the Board and the concerned Ministries as well as the PM's cabinet in arranging the overall long term financing of the Project with the best economic/financial terms for the Country (maturity, interest rates, tying with sourcing of equipment and/or contractors, fees, etc.) up to the Financial Close,
- General Hydropower Construction Consultancy Services to assist the Board and the concerned Ministries in the discussion in relation to the sale of electricity to national and international offtakers, and to the proper conduct and finalization of the procurement process (answers to the bidders, management of the bidding process, evaluation of the bids, discussion with the selected contractors with the view to conclude the construction contracts, etc.),
- Environmental and Resettlement Consultancy Services to assist the Board in the difficult and important task to plan and prepare the implementation of proper mitigation measures and the recommended development plan.

15.3.3. The Construction Period

Here also due to the exceptional nature and size of the Project as recalled here above as well as its international orientations, it is advised that the Board, or any future nominated entity associates with 2 high levels Consultants in the following fields:

- **General Hydropower Construction Consultancy Services to act as the Employer's Representative** for the management of the Construction Contracts until the commissioning of the Units of the Project and the issuance of the Final Completion Certificates. Although the overall Project includes 3 construction contracts (Preparatory Works, Dam Works, Power Component and HV Transmission Line), it is advised that a single Employer's Representative be selected for the full Project. The composition of the teams of the ER will be different for each of the 3 contracts. Of course the Board or any other nominated entity who will become the Employer of the Project, shall recruit local personnel to strengthen their resources and ensure the obligations of the Employer which have not been delegated to the ER.

  It should be noted here that to ensure as well as possible the efficiency and quality of the services of the ER, the experts and specialists who will be part of the ER's teams are also involved in the Consultancy Services required by the Owner/Employer at the Pre-Construction Period as set out here above ("the General Hydropower Construction Consultancy Services"). The continuity of the services' provider and his personnel between the Pre-Construction and the Construction Periods is, hence, recommended.

- **Environmental and Resettlement Consultancy Services** to assist the Board ("the Employer") in the tasks to manage the mitigation measures and development plan, as well as the corresponding implementation contracts.

15.4. The Scope of the Work of the Employer's Representative ("the ER")

15.4.1. General

The magnitude of the Project being exceptional, the quality of the design and of the construction supervision and management is of utmost importance and the ER shall devote its best teams on the site and in the head office to perform the highest standard services able to reach the required quality and bring to the Employer the assistance he requires.

Under this situation, it cannot be overstressed the importance of maintaining a permanent control over the activities of the Contractor, basically aimed at verifying that the design and construction comply with the optimum technical standards and with the Employer requirements and that the project implementation is carried out within the allocated time.

In order to achieve the above objectives, the following scope of services to be provided by the ER is listed hereinafter:

- Check and control the final design and construction design documents produced by the Contractor(s) (Civil Works, Hydro-mechanical and Electrical Equipment and more generally all Permanent Works items' design documents).
- Check the manufacturing, factory assembling, testing and preparation for shipment of the hydro-mechanical and electrical equipment.
- Check the programs for producing construction design documents and manufacturing of equipment issued by the Contractor(s).

- Check and control the methods and procedures to be used in the design and manufacturing by the Contractor(s).
- Check and control possible design changes due to geological or other conditions in accordance with the provisions of the EPC Contract.
- Handle claims originating from the Contractor(s).
- Ensure that the quality control of all construction, erection, testing of equipment and the commissioning activities carried out by the Contractor(s) are performed properly (Quality Assurance Activity).
- Ensure the Health and Safety regulations and obligations as well as the project site security obligations are planned, implemented, monitored and maintained by the Contractor(s)
- Verify that the progress of Contractor activities is proceeding according to agreed schedule.
- Check, evaluate and approve the payments invoices issued by the Contractor.
- Check and verify the integration of the interface of the power plant into the Interconnected System.
- Provide technical and contractual assistance during the General Defects Liability Period.
- Monitor that all activities are carried out in accordance with the national environmental regulations and that all negative environmental impacts (including the problem of resettlement) are minimized by the Contractor.
- Report periodically on the above matters to the Employer.

15.4.2. General Project Organization

Optimal planning and implementation of the Project recommend that efficient use is made of local resources and those of the expatriate and that a satisfactory level of coordination between their respective organizations is achieved.

It is therefore imperative that a clear project organization be established at the beginning of the Services. Since the Services to be provided mainly consist of design review, management and supervision of EPC type contracts, it is predictable that daily interaction occurs between the ER and the Employer, at least for all activities undertaken in Nepal.

The main positions of the Employer and the ER are the following:

- Employer's General Manager,
- Employer's Project Coordination Office; this Coordination Office will act as a liaison between the Employer, the ER, various agencies and government bodies associated with matters related to the Project, assuring liaison among the different parties involved in the Project implementation.
- Employer's Project Coordinator

  Project Coordinator (from the Employer) shall manage the Employer's Project Coordination Office and represent the Employer and be responsible to the Employer's General Management.

- ER’s Steering Committee

  the ER’s Steering Committee (SC) shall have full authority to deal with all technical, economic, financial, administrative, contractual and legal issues arising from performance of the Services and Contract. Proper delegation of authority will be made by the SC to the Project Manager, the Deputy Project Manager and the Chief Resident Engineer. The SC and the Project Manager will meet from time to time at regular scheduled interval or when the need arises.

- ER’s Project Manager

  The ER’s Project Manager is to be in charge of the Project and to be responsible for liaison between the Employer, through the Project Office, the ER and other Agencies.

  The Project Manager shall be responsible to the SC and shall conduct the day-to-day management of the services and the performance of the Contract. The Project Manager will be assisted by the Deputy Project Manager for any issue related to the performance of the obligations of the ER under the Contract and the Chief Resident Engineer for all site matters.

- Head office support in respect to mobilizing staff for the assignment and providing technical support will be provided, as required.

- In order to provide a quality assurance check, external to the project, the ER will establish an “Internal Board (Panel) of Experts” consisting of senior technical specialists (with internationally recognized expertise, each one in his field), to constitute a permanent “internal review team”. The size and make-up of the team will vary depending on the stage of the project.

- Employer’s Panel of Expert: The Employer may wish to appoint an independent Panel of Expert for periodic reviews of key technical issues. Depending on the composition of the ER’s Internal Board of Expert, this second Panel of Expert might not be required. There are numerous large Project organizations which do not have this double level of Expertise review.

- Executive Advisor; due to the huge size of the project, the highly compressed time schedule and t he necessity of assuring the most efficient and timely accomplishment of the construction works, the project will benefit of the extensive services of the Executive Advisor (EA) who will advise and complement the Project Manager activity in both technical and managerial services, without any duplication. The absolute efficiency of the Consultant’s Team will be im plicitly guaranteed by the fact that the Executive Advisor is also one of a member of the Steering Committee, allowing the m ost reliable and timely process of “decision taking”.

- ER’s Chief Resident Engineer

  The Chief Resident Engineer shall assist the Project Manager for the day-to-day activities performed in principle at the Project site and shall be responsible to the Project Manager.

The Chief Resident Engineer shall be assisted for the coordination and liaison activities by an Ex pediting and Liaison Officer, residing in Ka tmandu and managing the ER's Project Office in Katmandu, to be used mainly for coordination meetings arranged by the ER specialists travelling to Nepal for periodical visits of the site works and by the ER resident staff, coming sometimes to Katmandu to discuss the progress of the construction works.

As refers to the ER' services, the majority of the activities related to Engineering Review of Final and Construction Design will be carried out at the ER's head offices but any major decisions on design issues will be taken jointly with the Employer after thorough discussion and exchange of views between the Employer and the ER. These discussions may take place at the Project Office.

On the other side almost all activities related to project management and supervision as well as the activities related to project commissioning will be c arried out at site in tight collaboration with the Employer's personnel.

Quality Control activities will be carried out both at the ER's head offices and at site, while factory inspections will be performed at the different suppliers' workshops.

15.4.3. Head Office ER's Organization

The already mentioned ER Organization Chart of Table 15-1 is self-explanatory. Under the supervision of the Employer's Project Office the working teams will be headed by the Project Manager, with the assistance of the Deputy Project Manager, who will be responsible for all the ER's Head Office activities and all the activities of the resident staff at site.

The design review team will be managed by the Coordinator of the Design Activities, who will provide general quality control of the design review; he will interface with the Contractor design team.

As mentioned above, the activities at site will be directed, coordinated and supervised by a Chief Resident Engineer acting as Resident Project Manager, under the management of the Project Manager.

For the ER's Head Office activities, including the required missions at site, the Project Manager will be assisted by a group of experts and specialists in the different activity fields of the Project.

The identified specialists are the following:

- Coordinator of Design Activities
- Hydroelectric Plant / Reservoir Operation Specialist
- Engineering Geology Specialist
- Geotechnical / Rock Mechanics Specialist
- Foundation Treatment Specialist
- Arch Dam Design Expert
- Finite Elements Modelling Specialist
- Hydraulics Specialist
- Civil / Hydraulic Works Specialist

- Structural Engineering Specialist
- Construction Methods Expert
- Hydraulic Turbine Expert
- Hydro-mechanical Equipment Expert (gates, linings, trashracks, etc…)
- Electrical and mechanical Equipment Expert
- Generator Equipment Expert
- Control System Expert
- Transmission Line and substations Expert
- Environmental & Social Impact Specialist
- EPC Contracts / Claims Expert

15.4.4. Organization in Nepal

The ER's Organization Chart in Nepal proposed to undertake the site services is also shown in the Table 15-1.

The site activity management team will be headed by the Resident Engineer (Resident Project Manager), who will be posted mostly at site.

A Project Office shall be established in Katmandu, headed by the resident Expediting & Liaison Manager, who will permanently keep the relations between the ER and the Employer's Office.

In addition to the expatriate management team (the Site Manager and Expediting and Liaison Manager), the following ER's personnel have been foreseen at site:

- Contract Management Engineer
- Technical Office Engineer
- Implementation Schedule and Cost Control Engineer
- Engineering Geologist #1 (dam and powerhouse areas, quarry & borrow area)
- Engineering Geologist #2 (underground works)
- Dam Area Supervisor
- Dam Area Deputy Supervisor
- Foundation Treatment Supervisor
- Underground Works Area Supervisor
- Powerhouse Area Civil Works Supervisor
- Other Open Air Concrete Works Area Supervisor
- Preparatory Works Area (access roads, camps, energy and water supply, etc…) Supervisor
- Concrete Manufacturing & Laboratory Testing Supervisor
- Turbine & Ancillary Equipment Erection Supervisor
- Hydro-mechanical Equipment Erection Supervisor

- Electrical and mechanical Equipment Supervisor
- Generator Equipment Supervisor
- Control System Supervisor
- Commissioning Coordinator
- Quality Assurance Supervisor
- Health and Safety, Security Supervisor

During Commissioning phase, the Commissioning Coordinator will be responsible of all commissioning activities with the assistance of the “hydro” and ”electro” mechanical equipment Supervisors and the Control System Supervisors.

The Contract Management Engineer, the Technical Office Engineer and the Implementation Schedule / Cost Control Engineer will operate mainly at site but also at Katmandu, when required.

To enhance the in-house capability of the Employer’s personnel in project supervision and also to render additional services, Employer’s engineers, technicians, inspectors and supporting staff shall be assigned to the Project site to work with the ER as much as required.

15.4.5. Employer’s Representative organization at Site - Local Staff

The ER requires the Employer to provide engineers, technicians, inspectors and supporting staff to work in tight cooperation with the ER’s team; the Consultant, as part of the Quality Management Plan, will evaluate the Employer’s staff. The site organization chart is shown in the Table 15-2 thereafter.

15.5. Institutional Arrangement for Environmental and Resettlement Aspects

The implementation of the Environmental Action Plan (EAP) and Land Acquisition and Resettlement and Rehabilitation Action Plan (LARRAP) has to be carried out in parallel with the preparatory works on site and with dam and powerhouse construction.

In line with the best international practice, it is advisable that the resettlement should be completed at least one year before the reservoir begins being impounded.

As mentioned earlier, it is recommended that a specific environmental and social section should be set up within the Owner’s organization. This department will be dedicated to the management of detail design of the environmental and resettlement action components, and to management of the implementation thereof.

The environmental and social section should be staffed with experienced personnel in the field of management of EAPs, resettlement action plans and regional development plans. It could be composed as a minimum of the following personnel: a manager, a deputy-manager, a socio-economist with proven track record in involuntary resettlement, an agronomist, and an environmental expert.

In addition to the management of the corresponding contracts, this department will be the focal point for permanently liaising with:

- such Ministries of GoN as the Ministry of Agriculture Development (MoAD), the Ministry of Education and Culture (MoEC), the Ministry of Federal Affairs and Local Development (MoFALD), the Ministry of Forest and Soil Conservation (MoFSC), the Ministry of Health and Population (MoH), the Ministry of Land Reform (MoLR), the Ministry of Physical Planning and Works (MoPPW), the Ministry of Science, Technology and Environment (MoSTE), etc,
- the local governments in the region of the project and the bodies representing the local population,
- interested national and international NGOs

The environmental and social section within the Owner's organization will need, in addition to its offices at the head-office in Kathmandu, permanent premises in the region of the project, may be both at dam construction site and e.g. in Arughat. It will also need adequate four-wheel drive vehicles etc.

The responsibilities of the environmental and social section will in particular include the following:

- compile the final register of the persons eligible to resettlement,
- prepare the final designs for the environmental and resettlement action components, or have them prepared,
- supervise the implementation thereof,
- disburse the cash compensations to eligible persons,
- monitor the implementation of the environmental action plan and of resettlement/rehabilitation,
- coordinate the treatment of claims,
- prepare the files for the completed environmental and social components of this project,
- etc.

Within the Employer's Representative organisation, the Environmental and Resettlement Consultancy will provide the following services:

- assistance to the check of final design of the environmental and resettlement action components,
- assistance to the monitoring of their implementation
- assistance to the coordination with GoN departments, local government and other entities.

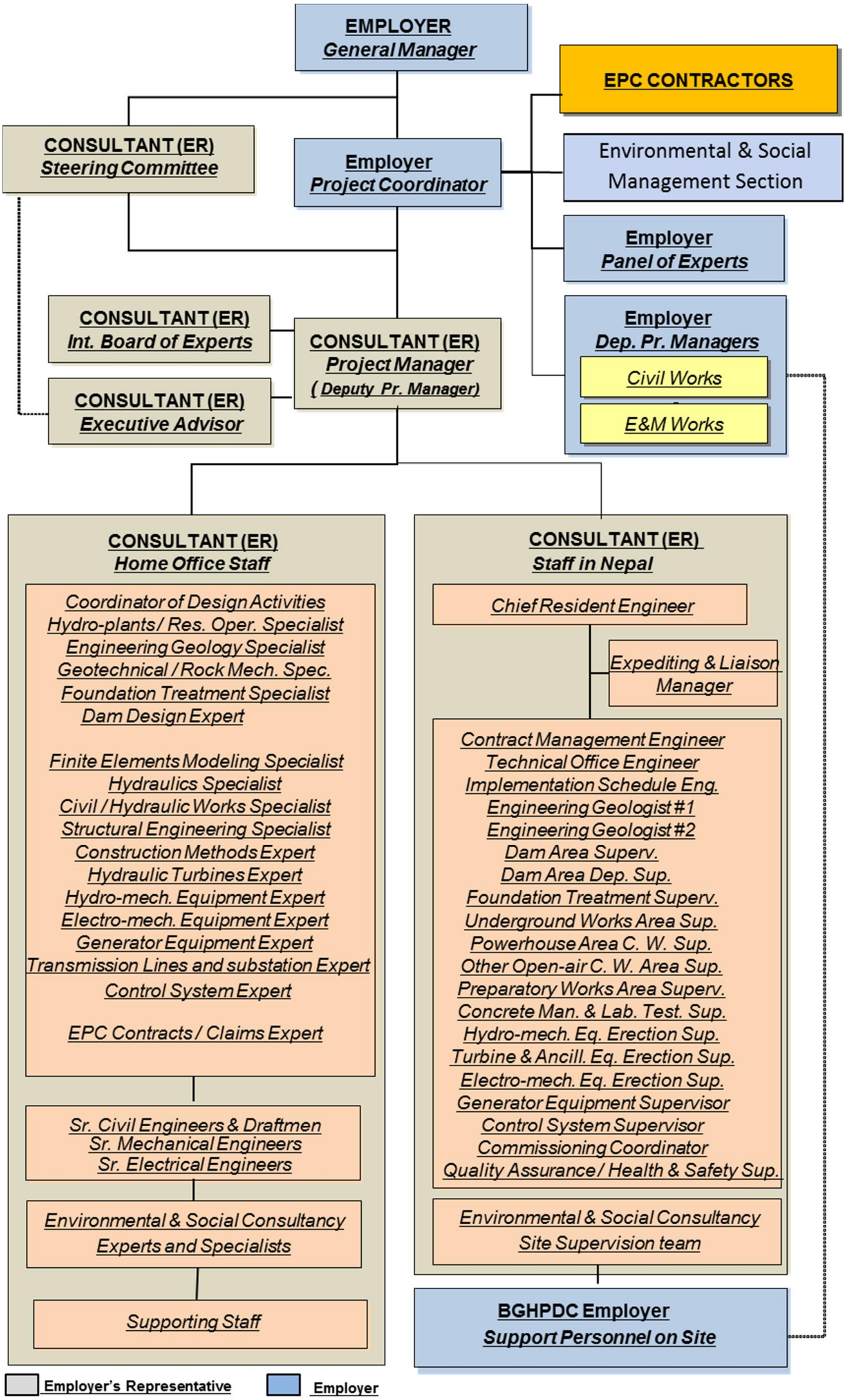


Table 15-1: Employer's Representative Organization Chart

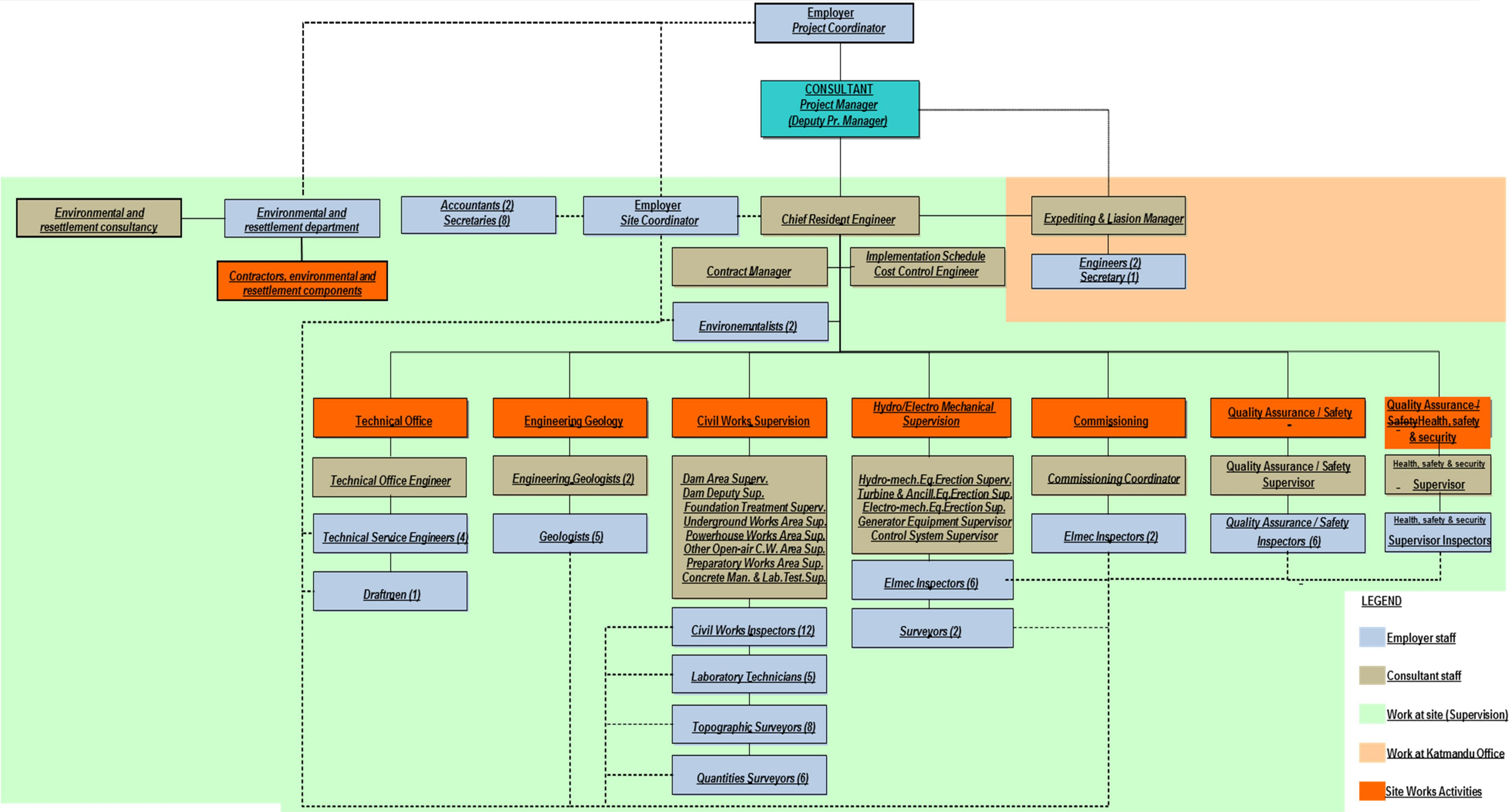


Table 15-2: Employer's Representative Organization Chart at Site

16. HYDRAULIC MODEL TESTS

A hydraulic physical model has been constructed and operated in Hydrolab (Kathmandu Nepal) for the detailed studies stage. The model aimed to analyze the hydraulic performance of the spillway and mid-level outlets of the dam and to conduct appropriate optimization.

The model includes a part of the upstream reservoir, the dam including spillway and mid-level outlets, the downstream river reach, such as the impact area of the outlets was also modeled. The river bed was modeled with a movable bed, with sand and small gravels so as to reproduce the natural alluvium composition of the river, the erodible character of the bedrock and evaluate the long term scour hole dimensions after the outlets operation.

Figure 16-1 Hydraulic physical model - Upstream views

Figure 16-2: Hydraulic physical model - Downstream view

Conceptual tests have been done, allowing to validate the satisfactory performance and the adequacy of the general arrangement of the spillway and mid-level outlets design.

The tests allowed evaluating the discharge capacities, the scour hole dimensions and location. These tests led to incorporate some minor changes in the design, in such way that the performance of the hydraulic organs has been optimized, and the downstream impacts in the plunge pool have been controlled.

The following figure illustrates the operation of all spillway outlets, and downstream air jets.

Figure 16-3: Hydraulic physical model – Spillway operation before optimization

After the first tests, adjustments were made on the spillway and mid-level outlets design:

- The tests has allowed to evaluate the flip buckets efficiency, and concluded on the fact that the original triangular shaped flip buckets leads to a dissymmetric discharge distribution along the outlet width, except for Mid-Level outlets. The first adjustment consisted in changing the flip buckets design to symmetrical square buckets.

- The take-off angle of SPW1 was also adjusted so as to obtain a good hydraulic behavior over the flip bucket, while keeping a safe impact distance, with regards to the downstream dam toe.

- The horizontal orientation of spillways 4 and 5 was adjusted 4° towards the river axis so as to reduce the lateral extension of the impact area.

- Consequently, the take-off angle of spillways 2 and 3 has been reduced so as to avoid interaction of air jets from SPW2 with SPW4, and SPW3 with SPW5.

- The model tests results allowed also to confirm the benefit of implementing a downstream tailwater dam to increase the downstream water levels within the plunge pool so as to give a better control over the scour hole formation on long term behavior.

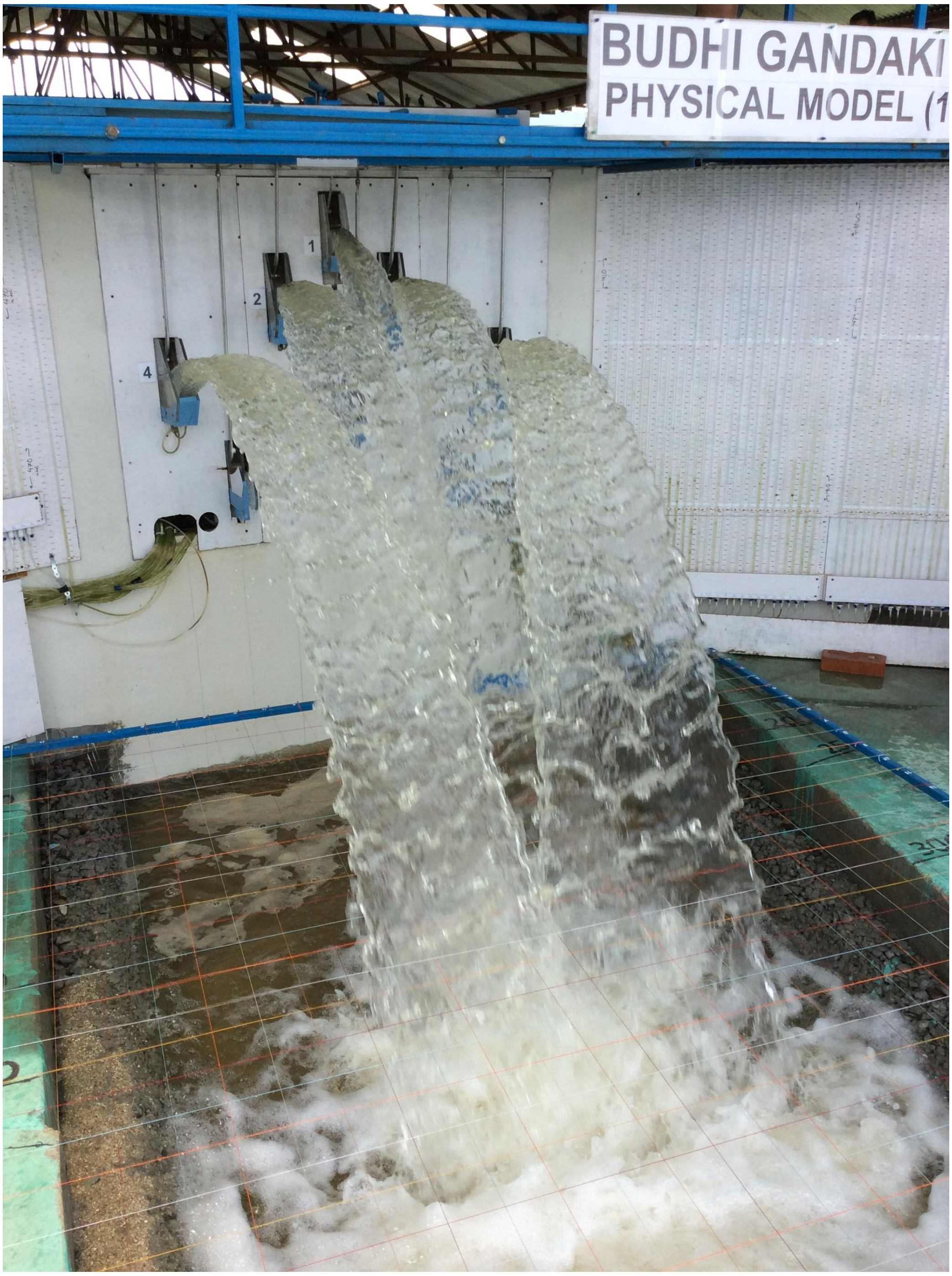


Figure 16-4: Hydraulic physical model – Spillway operation after optimization

Figure 16-5: Detail of spillway flip buckets and jets

Figure 16-6: Visit of BG HPP Hydraulic Scale Model by BGHPDC on 26 June 2015
Chairman Mr. L.P Devkota and Executive Director Mr. Gopal Basnet

In conclusion, the assumptions made for spillway and mid-level outlets design were checked and validated by the physical model tests, which allowed confirming the very satisfactory hydraulic behavior and performance of these structures.

The tests allowed to make minor adjustments on some features of the design, such as take-off angles of flip buckets, orientation of outlets, and to draw conclusion on the advantages that can be provided by a tailwater dam, which gives a better control on plunge pool water levels, and consequently on the scour hole ultimate depth.

The full report presenting the Hydraulic Model Test is incorporated in the Final Field Investigation Report (Ref BG-INV-FNL Part B Hydrological, Meteorological, Sedimentological Investigation & Hydraulic Model Studies).

17. SALIENT FEATURES

1. Reservoir	
Full Supply Level (FSL)	El. 540 masl
Maximum Flood Water Level	El. 542 masl
Reservoir upper boundary incl. 3m freeboard	El. 545 masl
Minimum Operating Level (MOL)	El. 496 masl
Minimum Operating Level Ultimate (MOL.ult.)	El. 467 masl
Minimum Reservoir Level (MRL)	El. 440 masl
Reservoir Bottom Level	El. 326 masl
Gross Capacity (at FSL)	4 467 Mm^3
Active storage between FSL and MOL	2 226 Mm^3
Reserve Live Storage between MOL and MOL.ult.	952 Mm^3
Conservation volume between MOL.ult. and MRL	582 Mm^3
Dead Storage between MRL and reservoir bottom	708 Mm^3
Surface Area (at FSL)	63 km^2
Surface Area (at MOL)	39 km^2
2. Hydrology	
Catchment Area	5 005 km^2
Long Term Average Flow	222 m^3/s (see note at the end of this table)
Construction Flood (20 years)	3 070 m^3/s
Design Flood Discharge (10 000 years)	6 260 m^3/s
GLOF	3 000 m^3/s
LDOF	5 200 m^3/s
Probable Maximum Flood	9 800 m^3/s
3. Sedimentology	
Sediment inflow	9.8 million m^3/year
Active storage loss after 50 years	7%
Active storage loss after 100 years	13%
4. Diversion System	
Design Flood	3 070 m^3/s
Tunnel section, lining	Horseshoe exc., inner circular concrete lining
Number of tunnel	2
Diameter	12 m

Lengths DT N°1 DT N°2	 408m 438m
Crest Elevation of U/S Cofferdam	El. 357 masl
Crest Elevation of D/S Cofferdam	El. 332.50 masl
5. Dam	
Type	Concrete double curvature arch
Crest Level	El. 542masl + 1.1m u/s parapet
Maximum Height (above dam foundation)	263 m
Crest Length / Width at base/ at crest	760 m / 80m / 8m
Upstream and Downstream Slopes	Variable
Construction materials:	
Conventional Vibrated Concrete (CVC)	1.92 million m3
Roller Compacted Concrete (RCC)	3.84 million m^3
Total Concrete Volume	5.75 million m^3
6. Spillway	
Type	Orifice gated spillway with flip bucket
Number of bays	6
Bay dimensions	Width 5.6 m – Height 8.4 m
Crest Level	1 at El.515 masl / 2 at El.495 masl 2 at El.470 masl / 1 at El.460 masl
Design Flood (Routed)	6 280 m^3/s for PMF, 4 690 m^3/s for Q_{10000}
Gate Type	Radial gate with hydraulic hoists
Gate size	5.6 m x 8.4m, Six gates
7. Waterway and Powerhouse	
Intake structures	Bell mouth intake structures close to the dam on the left abutment
Total Rated discharge	6x112=672 m^3/s
Number of intake	6
Invert Level of Intake	El. 450masl HRT invert level at El.455.60masl
Gate Size- Stoplog and wheelgate	Span = 4 m / Height = 6m
Headrace Tunnel HRT:	
Number of HRT	6
Intake Tunnels	Ø 6m Concrete lined circular 107m Horseshoe Exc. Section

Headrace Tunnels	Ø 5.3m circular Steel lined 22mm From 87m for Unit 6 to 165m for Unit 1 Horseshoe Exc. Section
Pressure Shaft	Ø 5.3m circular Steel lined 28 to 45mm 140m high Circular Section
Penstock	Ø 5.3m circular Steel lined 45mm From 352m (unit 6) to 365m (unit 1) Horseshoe Exc. Section
Powerhouse and transformer building	Type: Outdoor in the left bank
Width, Length and Height	W 40 m x L 185 m x H 40 m
GIS building and potyard	Adjacent PH on platform at El.342
Width, Length and Height	W 60 m x L 112 m x H 15 m
8. Generating Equipment	
Turbine:	
Type	Francis Type, vertical axis,
Number of units in final stage	6
Net Head at Rated Water Level	200 m
Rated Discharge in finale stage	6 x 112 = 672 m^3/s
Installed Capacity	6 x 200 MW = 1 200 MW
Mean Annual Energy (Generation Scenario N°1)	3 383 GWh (see note at the end of this table)
Winter dry season Energy (Generation Scenario N°1)	1 408 GWh (see note at the end of this table)
Summer wet season Energy (Generation Scenario N°1)	1 975 GWh (see note at the end of this table)
Firm Power during dry season	from 1 200 MW 8h/day in Dec. to 934 MW 9h/day May
Firm Power during wet season	from 918 MW 7h/day in June. to 928 MW 4h/day Nov.
Turbine Rated Speed	230.8 rpm
Normal Tailwater level with 6 units in operation	El. 323.30 masl
Generator:	
Type	Vertical shaft revolving
Capacity in final stage	6 x 235 MVA = 1 410 MVA
9. Transmission Lines	
Number	2
Voltage	400 kV

Circuit	Double circuit
Conductor	Quad Bundle MOOSE
Length BG HPP to Naubise	40.3 km
Length BG HPP to Hetauda	58.7 km
10. Substations	
Number	2
Location	1 in Naubise and 1 in Hetauda
11. Costs	
Total Capital cost Environmental and Social Cost Civil Works HEM and E&M HV lines Infrastructures and roads Engineering and Administration	**2 593 MUSD** 612 MUSD 1 265 MUSD 571 MUSD 33 MUSD 55 MUSD 57 MUSD
12. Economic & Financial parameters	
Economical Internal Rate of Return **EIRR** Unchanged for Low, Medium and High load demand forecast (In nominal term)	Generation Sc N°1 Sc N°2 15.5% 16.9% (See note at the end of this table)
Financial Internal Rate of Return **FIRR** For medium demand forecast	Generation Sc N°1 Sc N°2 7.0% 8.6%
Average energy cost	US¢ 6.4/kWh
Capital recovery period	11 years
Energy Tariff For financing with 80% soft loan at 2% and 20% equity 100% Public Dev. and Return on Equity 10%: Mixed Public/Pvt Dev. and Return on Equity 20%:	Generation Sc N°1 Sc N°2 US¢/kWh 9 7 US¢/kWh 14.5 11.5
13. Benefits	
Energy sales from Budhi Gandaki HPP Downstream flood reduction Downstream increase of mean dry season flow of Naranyani river at Devghat and Gandak Barrage	see 12. Discharge +50% from Jan. To May
14. Manpower requirement	
Foreign Skilled Semi-skilled Unskilled **Total** (persons)	300 570 1 140 3 990 **6 000**

Note:

It is worth mentioning that the recent measurements made during the last five years (2010-2015) on the discharge of the Budhi Gandaki river at dam site and at the long term operated DHM gauging station in Arughat (since 1964) allowed to obtain a better relationship between the discharges at Arughat gauging station and those at the dam site (see also section 2.1).

The Consultant estimates that the river runoff at dam site is likely to be 26% higher than anticipated in the hydrological study of the Feasibility Report which has adopted a conservative approach in the transposition law between discharges measured at Arughat and those at the dam site since only few years of parallel measurements were available when editing the Feasibility Report.

This increase in the river runoff at dam site has a direct consequence on the BG HPP annual generation output called Generation Scenario N°2 which would be 26% higher i.e. reaching 4 250GWh per annum (1 620GWh in dry season or 10.8 GWh/day with guaranteed capacity of 970 to 1200 MW).

The Consultant considers that the 5 years parallel river discharge measurements Arughat-Dam Site are sufficient to have a reasonable degree of confidence in the new transposition law but recommends to continue the measurements at dam site to increase the data base and fully firm up the additional project generation potential.

(see also section 4.2 and 4.4 of this Volume 1 Main Report Ref BG-DDR-Vol 1 Rev0)